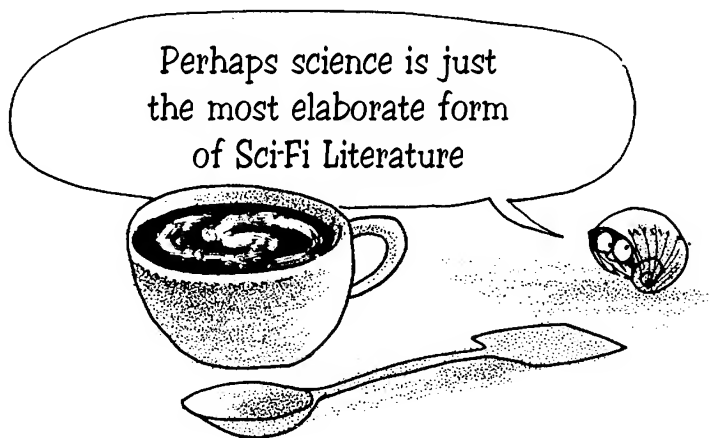


A THOUSAND BiLLiON SUNS

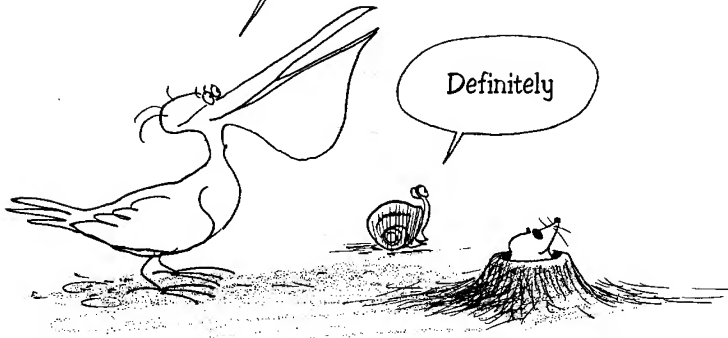
Jean~Pierre Petit

translated by John Murphy

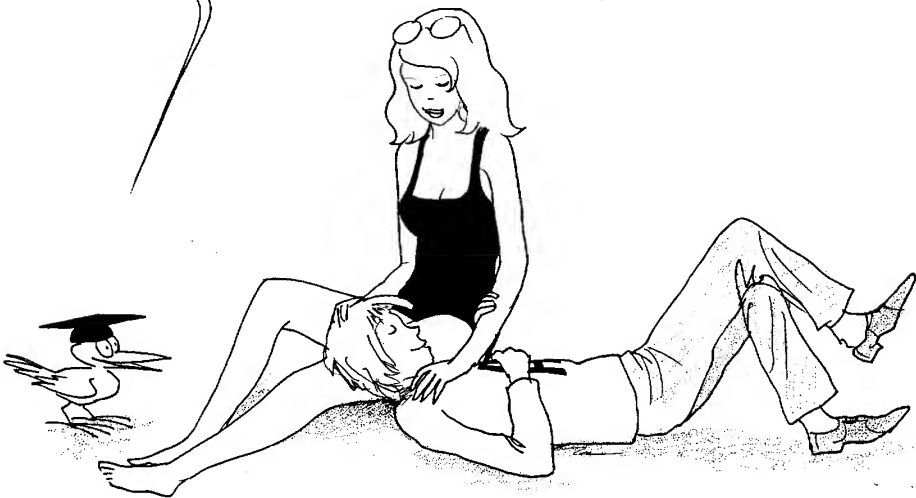


Are you certain that that's
Halley's comet Tiresias?

Definitely



It may be that the Universe
is just a vast operation of scientific vulgarisation:
God trying to help us understand something...



WARNING

ASTROPHYSICS is a **RECENT** science.

Until a few years ago man received his information through **THE DIRTY WINDOW OF THE ATMOSPHERE..**



The **GALACTIC DYNAMIC** is still waiting for its **KEPLER** or its **LAPLACE**. We still do not know how to construct a satisfactory mathematical solution to the equation system describing the object we call a **GALAXY**.

In this area, theoreticians have been treading water for over a century!

Paradoxically, the childhood of the Universe (**BIG BANG**) is better understood than its early youth, which is still... nebulous.

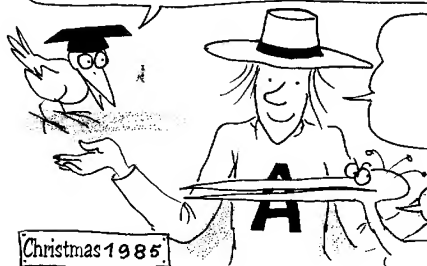
We're a long way from a consensus and perfectly contradictory theories exist concerning the birth and evolution of galaxies.

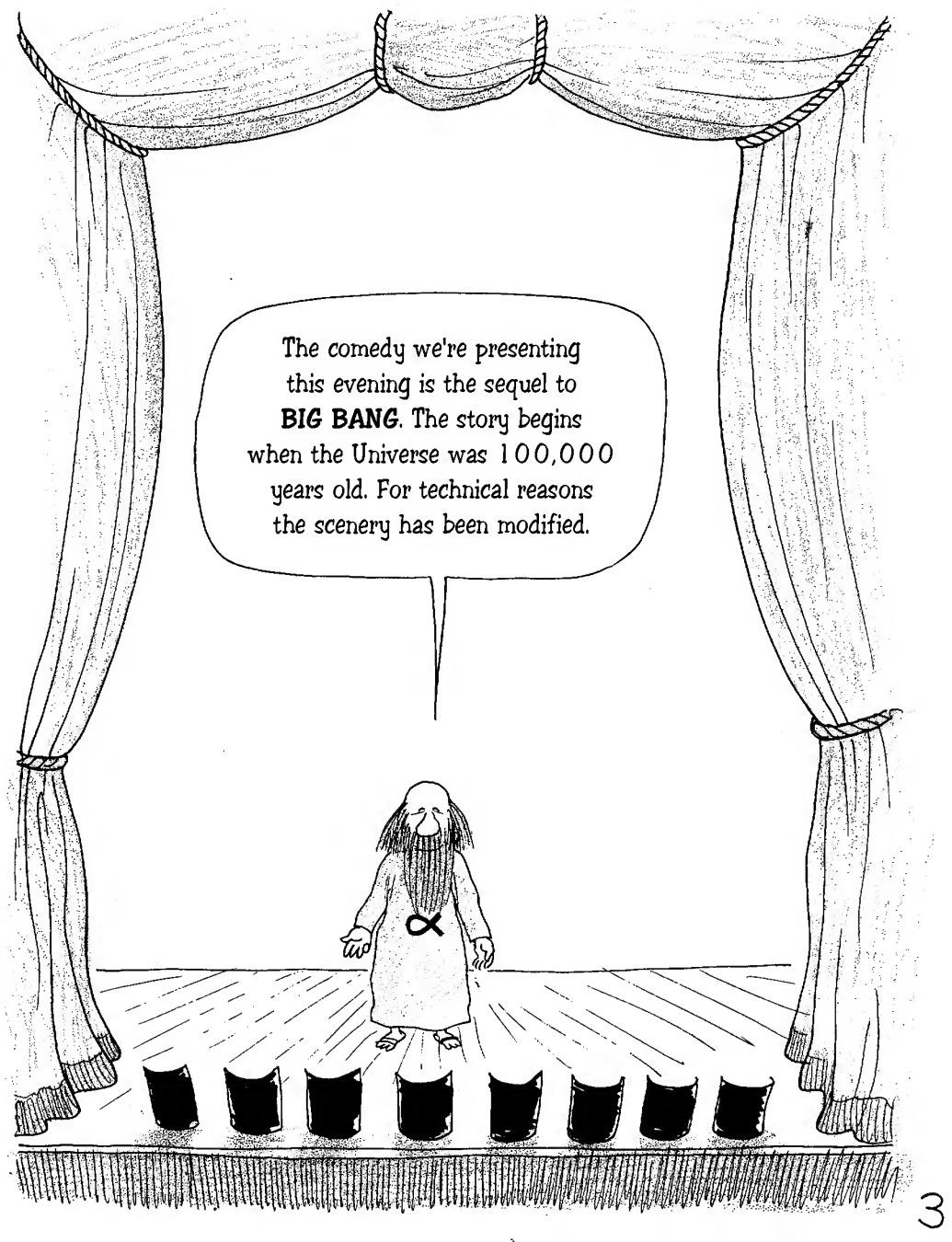
Information collected thanks to the space telescope, and treated by the most powerful computers, might allow us to arrive at something coherent in the future... more or less distant.

So the author has made personal choices. One day the following story will appear as a perspicacious synthesis.

Or as a load of nonsense.

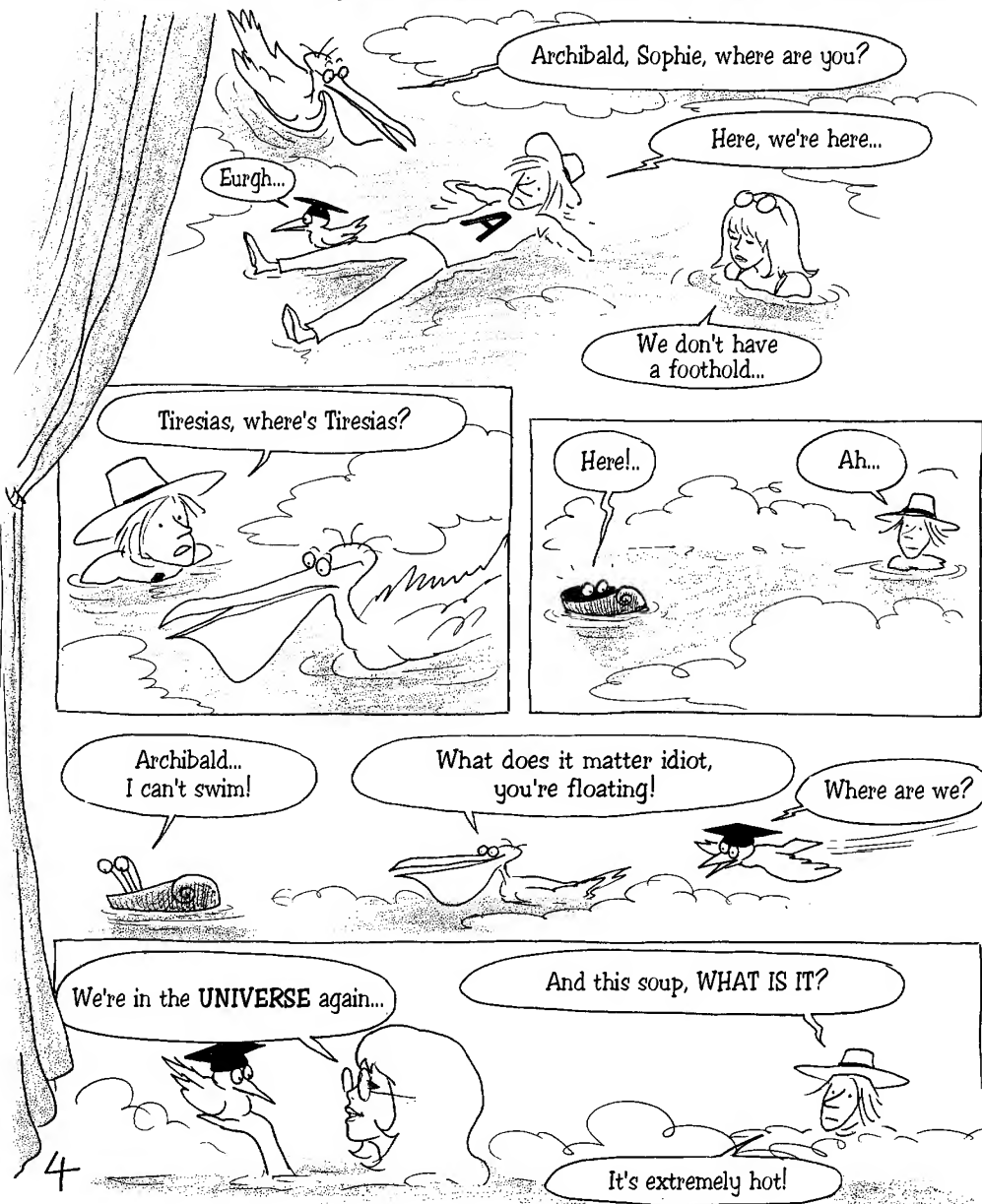
Christmas 1985.





The comedy we're presenting
this evening is the sequel to
BIG BANG. The story begins
when the Universe was 100,000
years old. For technical reasons
the scenery has been modified.

THE PLANET UNiVERSE



This soup, young fellow, is **MATTER**

Ah, you're
back again
then!

In the beginning
the spirit of God floated
above the waters...

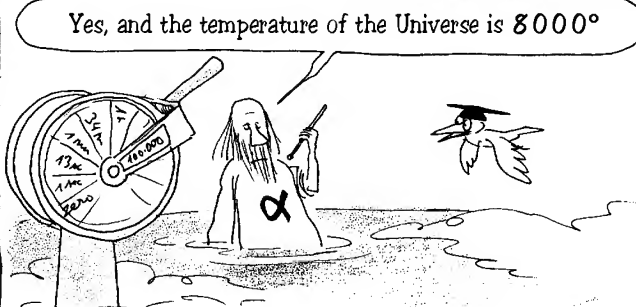
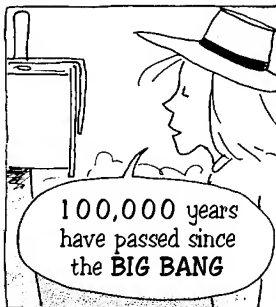
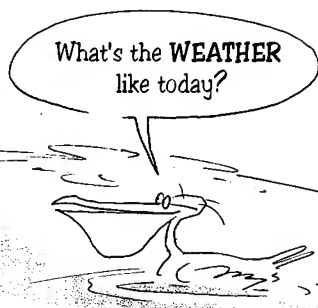
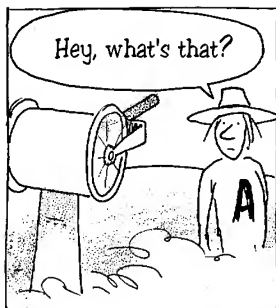
quick...

Stop,
iconoclast!

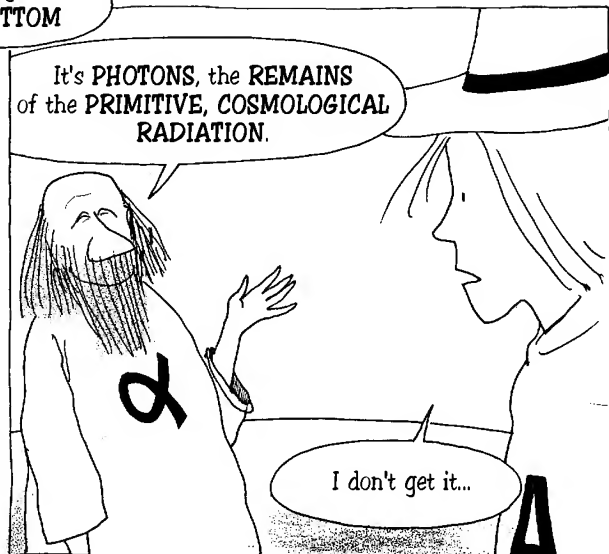
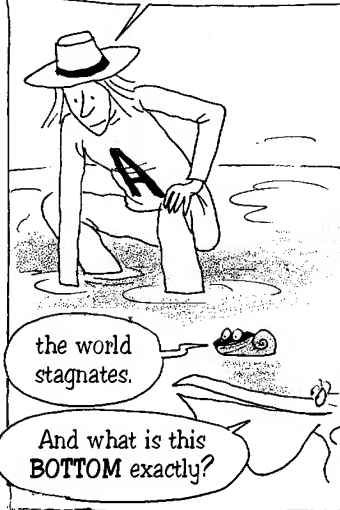
Oh look, it's a miracle.

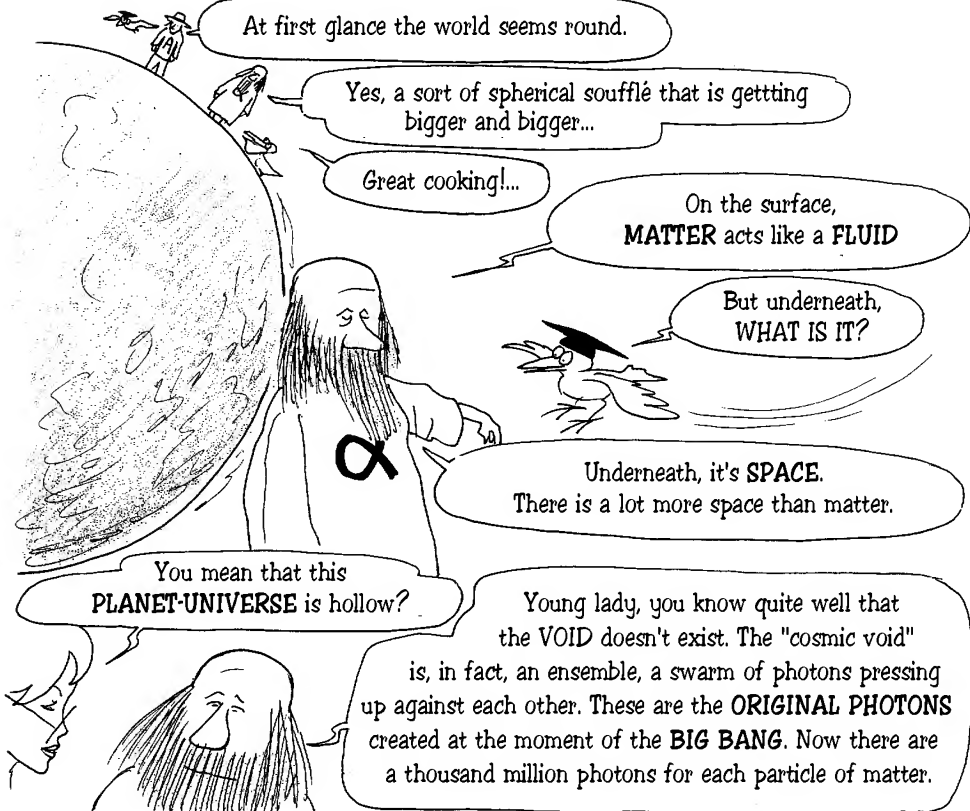
Not at all, he's just got a foothold...

Ah yes,
right enough!



The **FLUID-MATTER** is strange.
It seems like it sticks to the **BOTTOM**





At first glance the world seems round.

Yes, a sort of spherical soufflé that is getting bigger and bigger...

Great cooking!...

On the surface,
MATTER acts like a **FLUID**

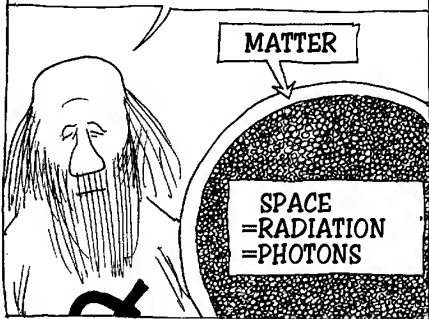
But underneath,
WHAT IS IT?

Underneath, it's **SPACE**.
There is a lot more space than matter.

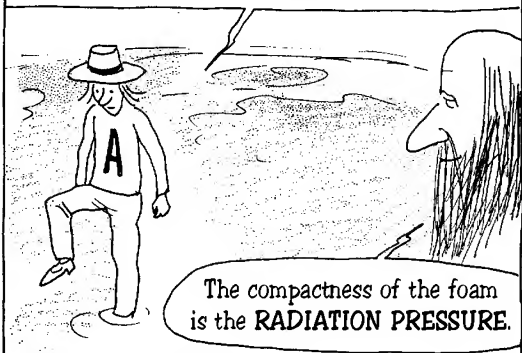
You mean that this
PLANET-UNIVERSE is hollow?

Young lady, you know quite well that the **VOID** doesn't exist. The "cosmic void" is, in fact, an ensemble, a swarm of photons pressing up against each other. These are the **ORIGINAL PHOTONS** created at the moment of the **BIG BANG**. Now there are a thousand million photons for each particle of matter.

In other words, the spherical soufflé is made of a sort of **ELASTIC** foam where each hole represents a photon (*).



ELASTIC? You call that elastic?
Your foam seems more like concrete to me!



The compactness of the foam is the **RADIATION PRESSURE**.

(*) The diameter of the holes corresponds to the photon's **WAVELENGTH**.

PRESSURE is something linked to **FLUIDS** isn't it?

Yes, but a group of photons is also a gas, which has pressure.

But the **VOID** is an ensemble of photons so the **VOID** is a gas! There's a thing!

In reality, **MATTER** and the "**VOID**", that is to say the original photon gas, form a **HOMOGENOUS MIXTURE**. But in this model, if I understand it correctly, you separated the two environments. The **EXPANSION** of this **PLANET-UNIVERSE**, which functions like a soufflé, makes the **RADIATION PRESSURE** decrease.

As well as that, the thickness of the "fluid-matter" simulates the **VOLUMINAL-MASS**, which also decreases.

So how do these two environments interact?

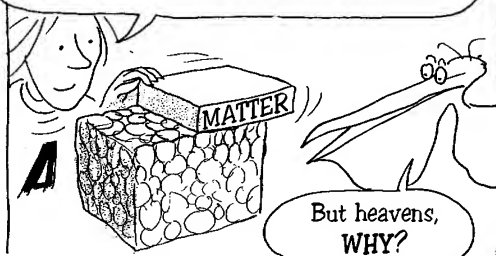
INTERACTION MATTER RADIATION

When the Universe had a temperature above 3000° , matter was tightly **COUPLED** to the background radiation, the original photons.

WHAT?

In the end it's as if matter was "stuck" onto the void.

Below 3000° , **MATTER** moves freely on the **BACKGROUND COSMIC RADIATION**.



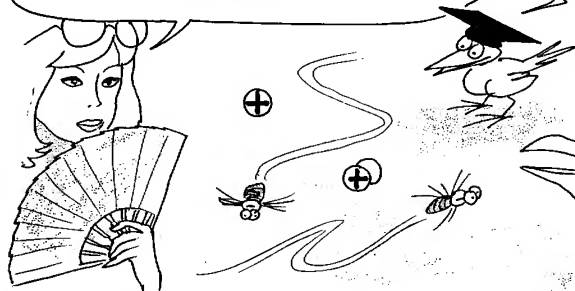
Leon, atoms are made of nuclei, positively charged, and electrons, negatively charged.



Hydrogen

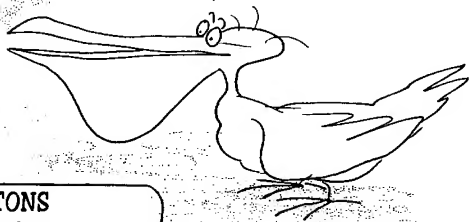
Helium

Above 3000° , **THERMAL AGITATION** becomes intense and **COLLISIONS** between atoms stop electrons from quietly orbiting around the nuclei.



The electrons thus become **FREE** and we say that **MATTER** is **IONISED**.

OK, and so what?



LIGHT corresponds to a movement of **PHOTONS** but it is **ALSO** an **ELECTROMAGNETIC WAVE**, an oscillation in space.

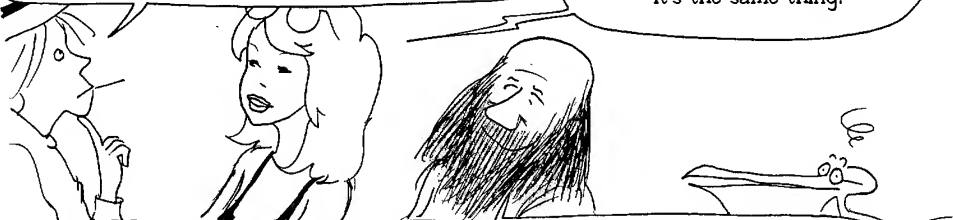


And this oscillation is felt more strongly by light electrons than by heavy nuclei.



An oscillation that propagates in a gas is a pressure wave ("), a sonic wave. So light would be a... radiation wave, propagating at 300,000 km/s.

In a gas the agitation speed of its elements is more or less equal to the speed of sound. In the "photon gas", it's the same thing.



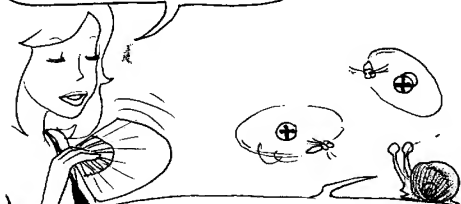
I must admit that this photon gas is one of my best inventions. In this case waves and particles **ARE ONE AND THE SAME**.

So, let's say:

- 1) An **IONISED GAS** interacts by rubbing against a "photon gas".
- 2) The "**VOID**" is, in fact, a "photon gas".
- 3) So ionised matter "sticks" to the void.

When the temperature of matter in the Universe drops below 3000°, electrons link with atoms and thus become a lot less sensitive to electromagnetic oscillations

The bond between **MATTER** and **BACKGROUND RADIATION** lessens and atoms can slide freely in the **VOID**.



They are "held" by nuclei.

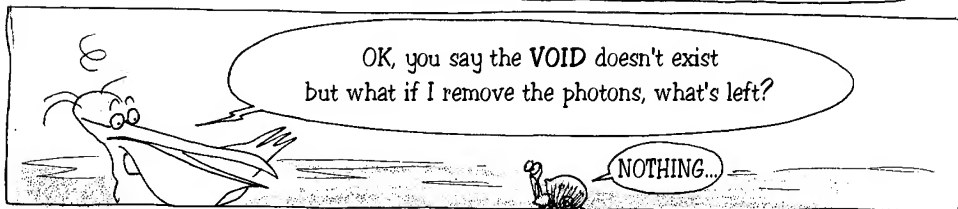




Hmmm. You tell me that
under our feet there is foam
with holes. I don't get it ...
PHOTONS aren't ...
fixed!?



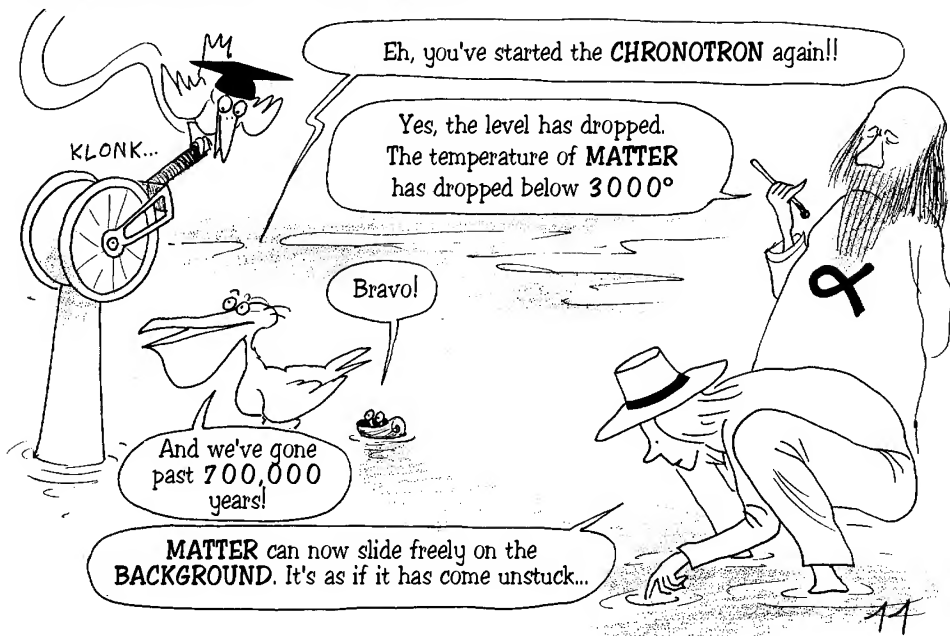
Leon, the story about the foam
was just a way of representing space and
the **PRIMITIVE RADIATION** it contains.



OK, you say the **VOID** doesn't exist
but what if I remove the photons, what's left?

NOTHING...

DECOUPLING



Eh, you've started the **CHRONOTRON** again!!

Yes, the level has dropped.
The temperature of **MATTER**
has dropped below **3000°**

Bravo!

And we've gone
past **700,000**
years!

MATTER can now slide freely on the
BACKGROUND. It's as if it has come unstuck...

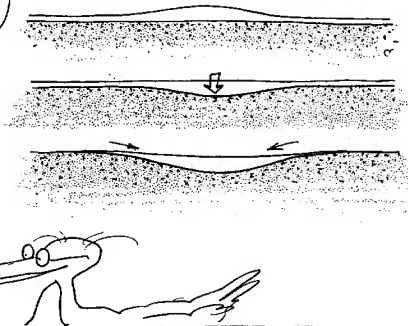
And that's not all, now matter is starting to collect in puddles

The background becomes more flexible. It seems to be pitting in various places and matter is settling in the dips.

Fluidmatter is heavy. It weighs on its support, which begins to sink.


GRAViTATIONAL iNSTABiLiTY

It's normal. When a concentration of matter appears, it **CURVES SPACE** and the neighbouring matter is drawn in (*).



A system forms puddles of **MATTER CONDENSATION** therefore





The dips aren't very deep in fact.

It's all pretty stagnant

The foam is still too **COMPACT** for deep pits to form. Even big pools only create tiny curvatures. You have to wait for the Universe to slacken for the support to have even a small amount of the elasticity needed.

RADIATION PRESSURE is still three tenths of thousandths atmospheres.

Three tenths of a thousand atmospheres !...
You call that excessive pressure?

GRAVITATIONAL FORCE is so weak that this pressure is enough to counter its effects.

Ah yes, it's true...
this force is the weakest of all those in the Universe.

So the compactness of the foam (radiation pressure) stops the support from creating dips and matter from condensing. The dilatation of the Universe lessens the compactness, this pressure. But how long do we have to wait before the force of gravity wins?

About 4.5 thousand million years.

While waiting, I'd like to know why all the dips are more or less of the same diameter, and why this diameter rather than another?

What do these condensations represent?

From ten to a hundred solar masses.

JEANS' LENGTH

And why are there dips? Why doesn't the Universe remain uniform. I'd like to know a good reason for such a phenomenon.

Of course. There's nothing better than a good experiment.

First I'm going to look at the behaviour of a concentration of matter on a **RIGID** surface.

It takes a little while to disperse, to spread out.

The force causing the matter's spread is **PRESSURE**, which incites it to take up as much room as possible.

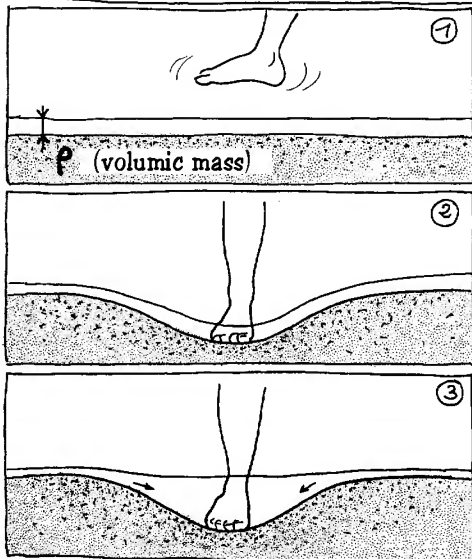
Apparently the time taken for a pool to spread, to double its dimensions, is proportional to its initial radius.

Secondly, the **HOTTER** the matter,
the **QUICKER** it disperses.

That's normal.
Temperature equals pressure:
the hotter the milieu, the more intense
the forces of dispersion, the pressure forces.

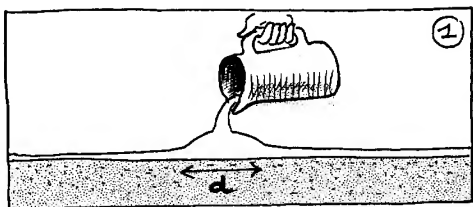
My goodness...
what a building site.

So I know more about the way a pool of matter
tends to disperse. B, phase number two: I don't
create **SUPERDENSITY**, but I do artificially
accentuate the curvature of the elastic support.

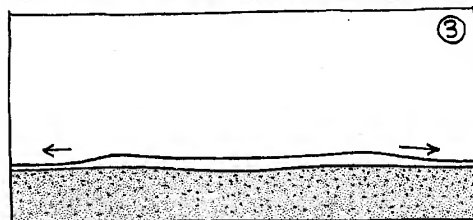
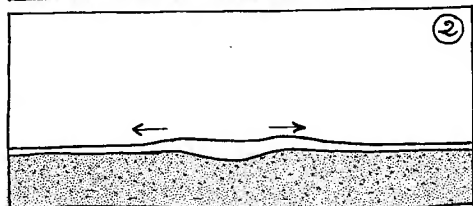


This artificially created
depression fills in a time
we call **ACCRETION TIME**,
which is as short as the
thickness of the fluid
(which simulates the
volumic mass)
is great.

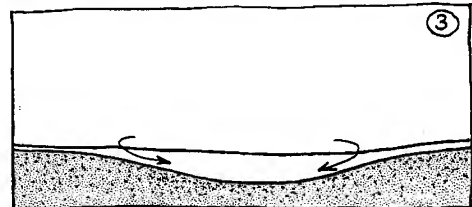
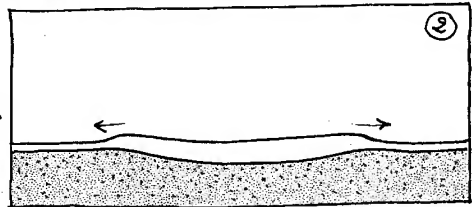
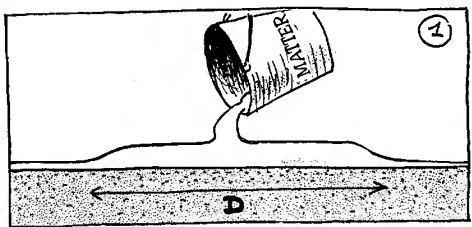
Now we have to conjugate
the two effects...



A small perturbation will have a short dispersion time. It won't have time to amplify and the dip will empty itself quicker than it fills.



However, a **LARGE** perturbation will have a **LONGER** dispersion time. It will fill more quickly than it empties and will have a tendency to amplify.



And I suppose that there's a critical radius beyond which amplification takes place?

Exactly, it's the **JEANS RADIUS** (or distance) ($''$), and the pools which form all have radii very close to the critical radius.



OK.

This **GRAVITATIONAL INSTABILITY** provokes the fragmentation of matter into those sort of lumps with a radius of the order of that of Jeans.
And so?

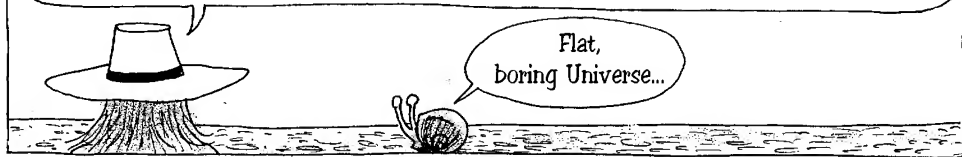
In these lumps, matter is compressed and heated. Its temperature increases to 3000° . Result: it ionises and is enriched with free electrons. The coupling between matter and the **BACKGROUND RADIATION** reappears. Matter "adheres" once more to the "void".

The matter will try to drag the support, the photon gas, with it. But as the background radiation is still lacking in elasticity it stops the lumps from continuing their condensation movement.

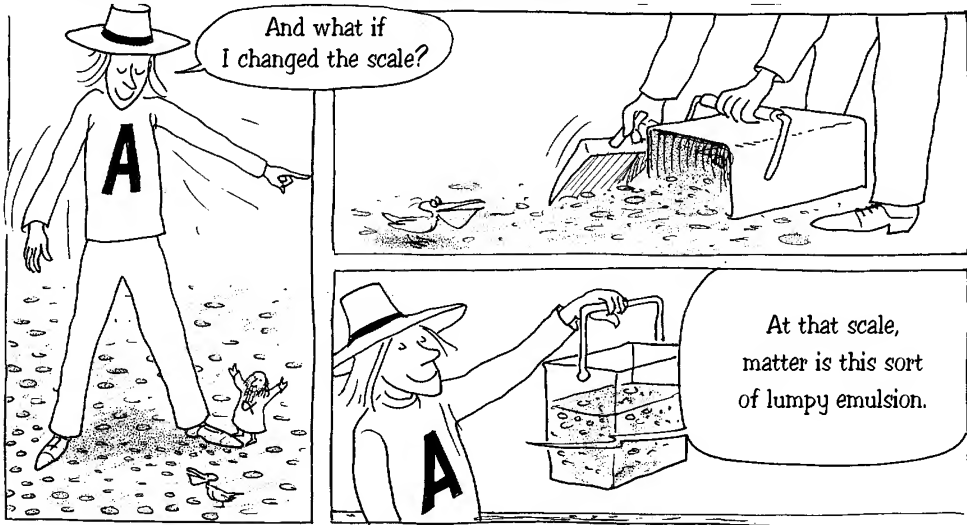
In other words, the Universe will be filled with these sort of things, whose temperature is 3000° , and with the mass of ten to a hundred thousand solar masses.



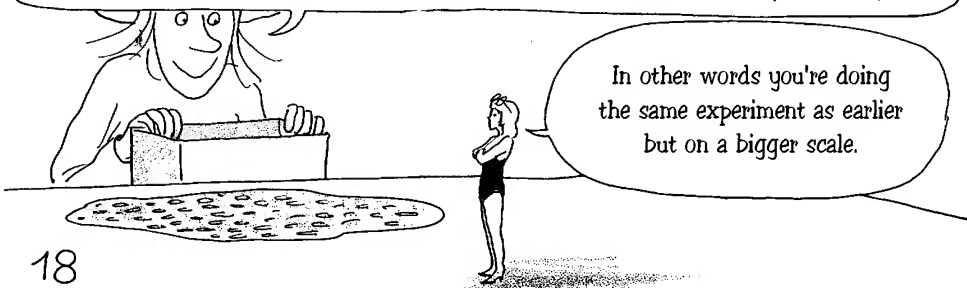
Nothing much happens after that. The expansion only separates the lumps from each other progressively. Before, the Universe was a mixture of hydrogen and helium atoms; now we could say it is an emulsion that extends further than we can see.



THE MACROCOSM



I'll tip it onto a rigid support and see how long it takes to disperse.
Then I'll do it again on a flexible support.



The new milieu also has its temperature, which is deduced, in the emulsion, from the agitation speed of the lumps (*).

In other words, there is a new tendency to fragmentation, on a bigger scale.

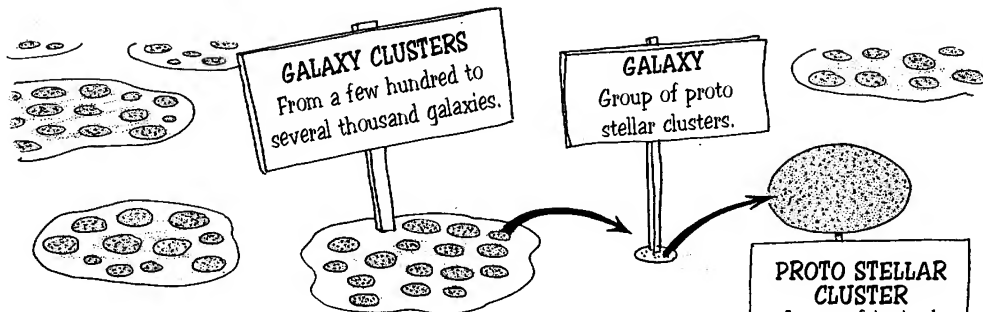
And that's how **GALAXIES** are formed.
Pretty don't you think?

Let's change the scale once more.

Simple, this fluid, considered as an emulsion of galaxies, will give rise to a new **FRAGMENTATION** phenomenon on a bigger scale.

The fragmentation will produce **GALAXY CLUSTERS**.

(*) The **TEMPERATURE** is the measure of the average cinetic energy of the agitation of the elements, in a fluid milieu..



The Universe is the seat of a
HIERACHICAL FRAGMENTATION
phenomenon.

I suppose it continues indefinitely.

Well NO, in fact!

Why?

If I brutally
create a depression in the
support LOCALLY ...

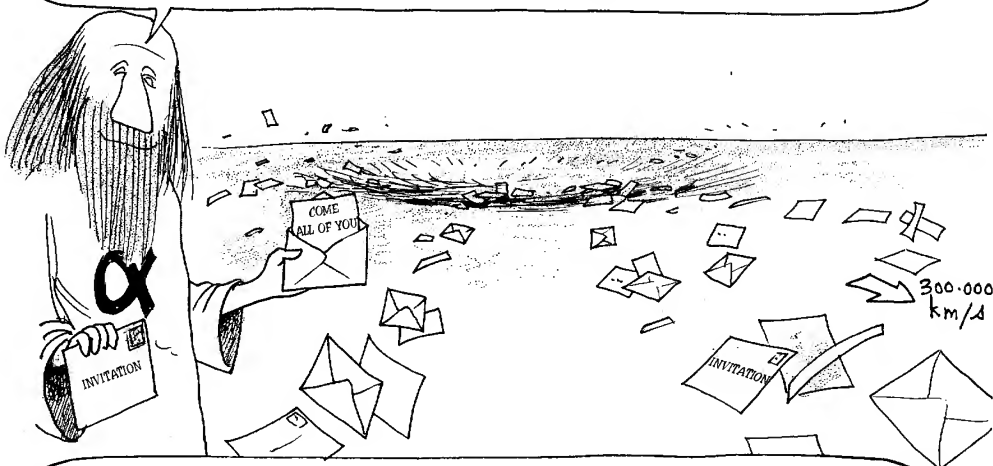
...this deformation, this surface
CURVATURE, will propagate all around
at a speed of 300,000 km/s

So it is light that is being propagated then?

No, it's a wave of curvature, a gravity wave

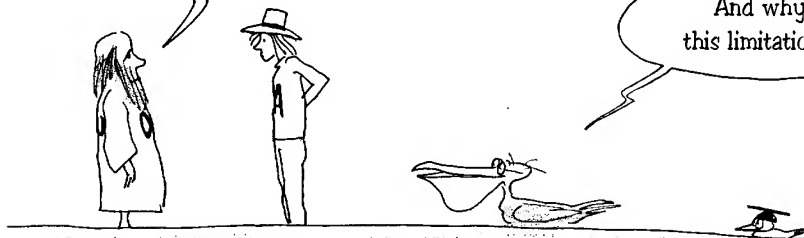
The **GRAVITATION FIELD** is propagated at the same speed as light

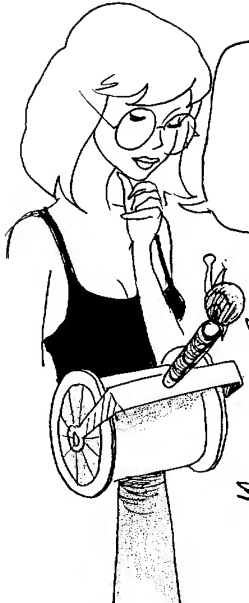
Through this propagation of curvature, all matter condensation "invites" surrounding matter to join it.



If a gravitational instability phenomenon occurs, interesting a region of space of diameter D , this will necessarily be inferior to Ct , where C is the speed of light and t the age of the universe.

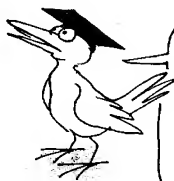
And why this limitation?





I've understood. Suppose that from France you want to summon people to a meeting to be held in 4 days. You could possibly invite everyone living in French territory but it would be impossible to invite those living outside because of the time required.

Of course. It's impossible to summon people to a meeting in less time than it takes for a letter to reach them.



The **CHRONOTRON** shows one hundred million years, **THEREFORE** the most vast structures that can exist now must have less than a hundred million light years diameter. That limits us to **GALAXY CLUSTERS**.



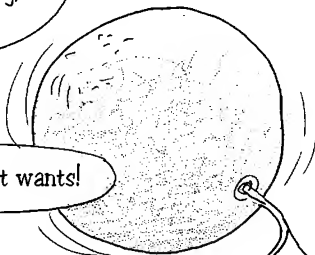
Those who are patient enough to wait for a dozen billion years will be able to see the constitution of **SUPERCLUSTERS** (clusters of galaxy clusters).

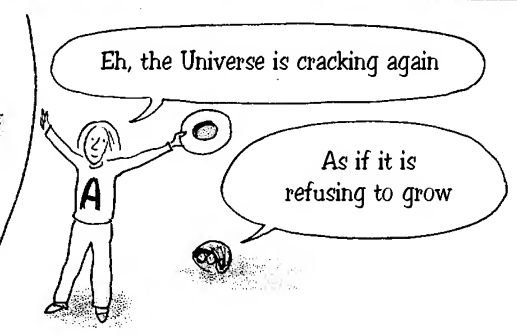
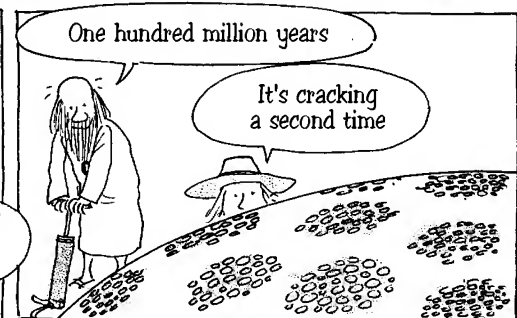
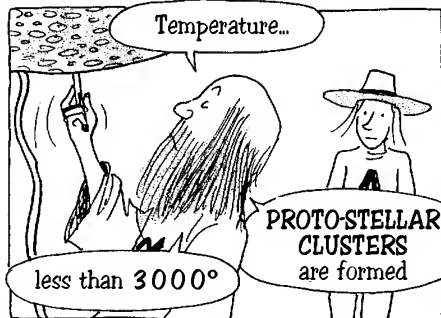
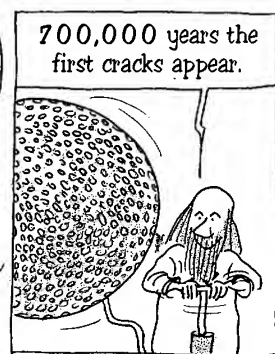
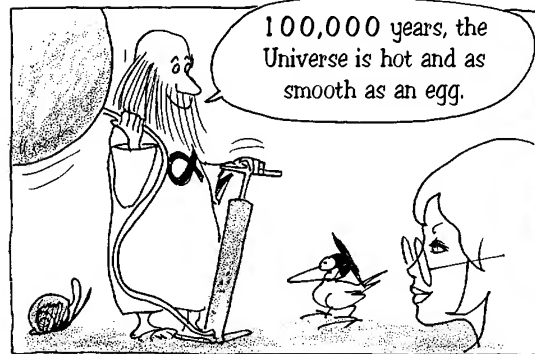
But the Universe is **EXPANDING**. Globally, it is dilating and locally, contracting...



It doesn't know what it wants!

You'll see...







We are at $t = 500$ million years. Galaxies are thus formed, even though they are still made up of lumps of gas at 3000° , proto-stellar clusters. They assemble in depressions: galaxy clusters. There they behave a bit like gas molecules and have erratic movements

The Universe is still very compact, galaxies will interact and be subject to **COLLISIONS**

COLLISION EFFECTS

Look, these two galaxies, or rather **PROTO-GALAXIES**, are going to brush against each other

a sort of bridge is created between them.

The bridge breaks

These encounters induce **ROTATION** movements in the **GALAXIES**

The same thing happens in a **GAS**. The same laws apply, on the scales of the infinitely great and infinitely small. **COLLISIONS** set the **GALAXIES-MOLECULES** into **ROTATION**. In this way the individual energy of galaxies will tend towards a distribution with equal shares of **TRANSLATION ENERGY** ($1/2 m v^2$) and **ROTATION ENERGY**. This energy equidistribution, or **THERMODYNAMIC EQUILIBRIUM**, is what all fluids tend towards naturally (*)

In other words, it's the encounters between galaxies that **CREATE** the rotational movement?

Only at the beginning. Young galaxies are subject to frequent collisions but **COSMIC EXPANSION** will soon distance them from each other and these collisions will soon become extremely rare.

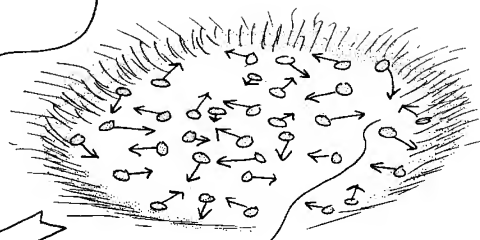
In other words the rotation movement we observe today is just a souvenir of a time when the **DENSER** universe formed a **COLLISIONAL ENSEMBLE**.

(*) Second Principle of Thermodynamics

The elements have **AGITATION SPEEDS** near to an average value. But, from time to time, chance collisions create extremely rapid elements and extremely slow elements.



SLOW SPEEDS **AVERAGE SPEEDS** **RAPID SPEEDS**



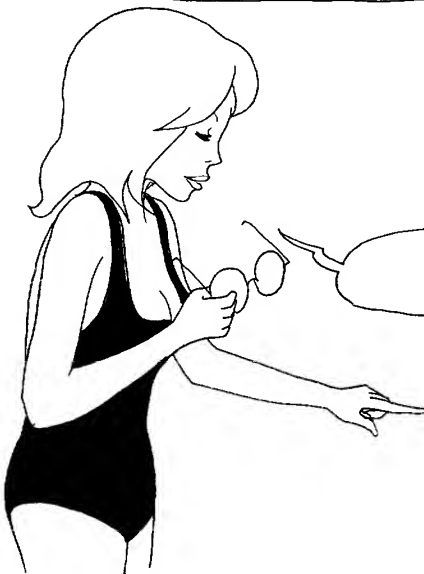
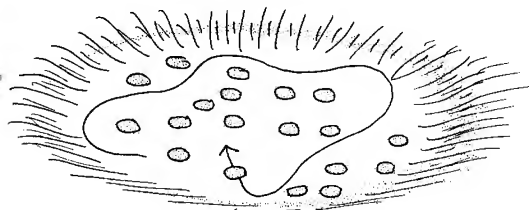
CIAO !

The elements, having thus acquired a superrapid speed, manage to escape from the dip and leave the cluster. This will happen if their speed goes beyond the **CLUSTER LIBERATION SPEED**.

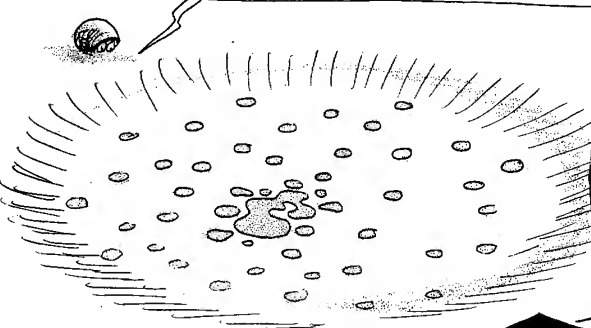


As this type of superrapid element is constantly created because of successive collisions, such an **AUTO-GRAVITANT SYSTEM** would have a natural tendency to lose its elements more or less quickly (*)

The vast majority of elements will simply go backwards and forwards in the dip.



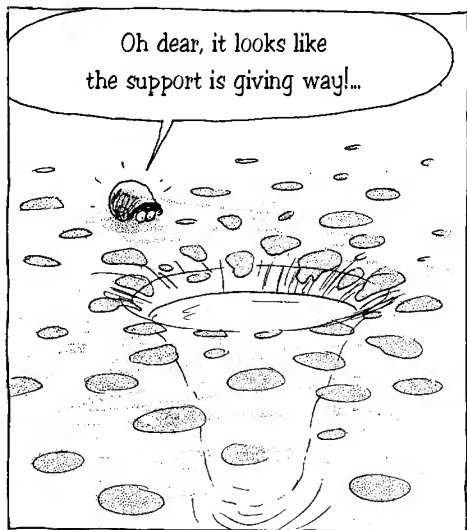
Inversely, these same chance collisions will create **SUPER-SLOW ELEMENTS** which will have a tendency to "fall" towards the centre of the **COLLISIONAL AUTO-GRAVITATIONAL SYSTEM** and will agglutinate. The centre of the **COLLISIONAL CLUSTERS** (where encounters between elements take place) will therefore have a tendency to enrich themselves with elements that are increasingly **MASSIVE**.



Look at what happens in the centre of this **GALAXY CLUSTER** for instance. **SLOW** galaxies agglutinate to give a **CARNIVOROUS GALAXY!**



The support is deepening considerably...



Oh dear, it looks like the support is giving way!...

BLACK HOLES

Max, help, it's collapsing!

Goodness!
Hang on
Tiresias!

KRAÂÂK

I can feel cracking
in my shell, hurry!

But not far from there...

Oh, you feel it?

What is it?
An earthquake?

Deep undulations are running through
the support, as if by curvature waves.

Something
must have **COLLAPSED**
somewhere...

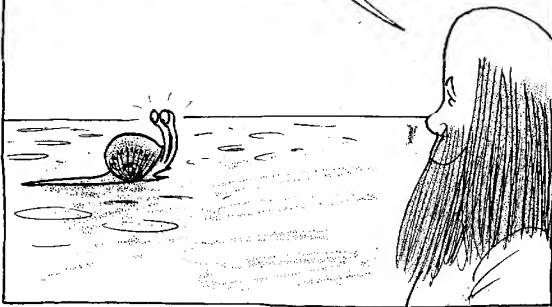
They **ARE** curvature waves, in other words,
GRAVITATIONAL WAVES.

It seems to be calming down



Max and Tiresias
are coming back.

It seems that our friend has just
managed to escape from a **BLACK HOLE**



Unfortunately the support of planet-Universe isn't
as solid as it could be. If we overload it, it gives way...



What an abyss!
We can't see the **BOTTOM**...



Normal, even
photons can't get out...



It was the **COLLAPSE** that created
the **GRAVITATIONAL WAVES** of earlier...

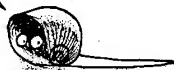
An odd thing

Don't go near it!

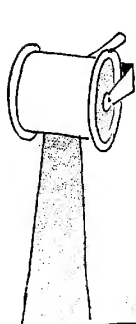


I'll never get out,
I'm using up
ALL MY ENERGY

So, to conclude, this Universe not only wants to collapse
but also, as far as impermeability goes, it's zero!



THE GREAT FIREWORK DISPLAY



The **CHRONOTRON** shows that billions
of years have passed. The Universe is
fragmented. **COLLISIONS** have set
GALAXIES into **ROTATION**.



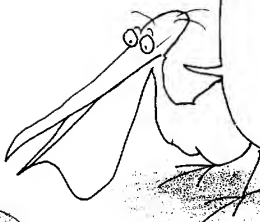
EXPANSION has distanced all these objects
from each other, to the point where they are now
unaware of each other.

In these "**PROTOGALAXIES**"
the basic element remains the
concentration of ionised atoms, the
PROTO-STELLAR CLUSTER, whose
temperature is close to **3000°**,
and which cannot collapse on itself
because of this "adherence" to the
BACKGROUND RADIATION

Anyone able to see the Universe
at that time would have seen woolly
nebulosities emitting diffused light.



The support has become more flexible.
The expansion of the Universe has reduced
RADIATION PRESSURE considerably.



How could **CONDENSATION**
of **MATTER** restart one day?

If the lumps condense their temperature
will automatically rise beyond 3000°
so adherence to the **BACKGROUND**
will never end, and this background
will be continually drawn into the
condensation movement won't it?

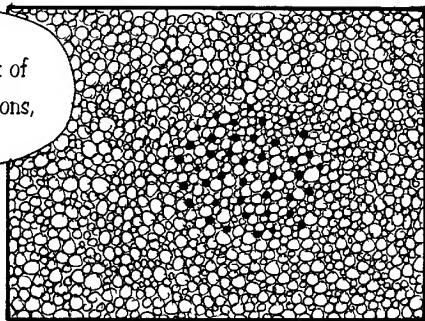


PROTO-STELLAR CLUSTER

Exactly Leon, but now the forces of gravity
in the proto-cluster will be able to "compress the **VOID**"
made up of low energy photons.



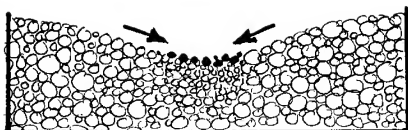
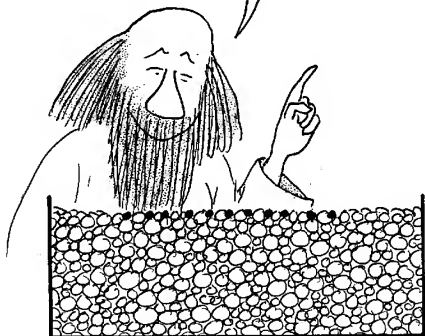
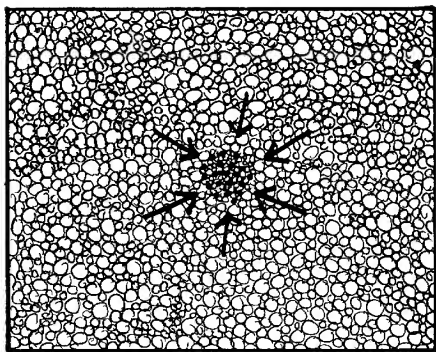
The region around the lump, where the
PROTO-STELLAR CLUSTER could be compared to a mix of
MATTER and "**EMPTINESS**", that is to say original photons,
the ensemble being at a temperature of 3000°



And when it condenses?



Matter isn't going to slide on space,
the cosmological background radiation,
but actually drag it with it, like this.



Wait, this happens at exactly the time when the radiation pressure
would have dropped below a certain critical value. Unless I'm wrong, when that
happens it will happen at the **SAME MOMENT** in the four corners of the Universe



It will be **FIAT LUX** (*).
Here, have some sunglasses,
it won't be long now...

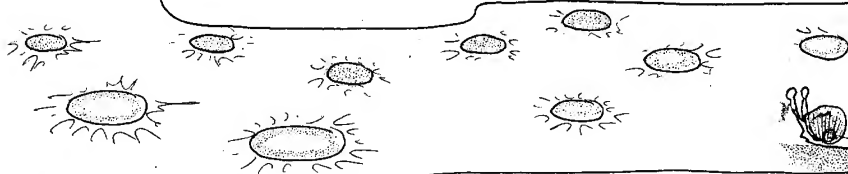
I must say I'm rather pleased with
a gadget that lets you set everything to start
at the same instant throughout the Universe.

Very clever. And it's starting



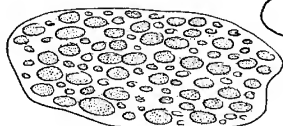
The PROTO CLUSTERS CONTRACT.

Their temperatures rise. The atoms emit a lot of ultraviolet energy and this manages to escape.

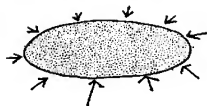
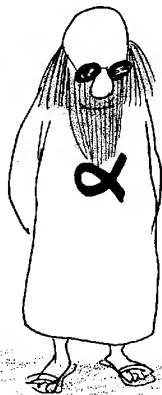


Look, the **PROTO-STELLAR CLUSTERS** are fragmenting.

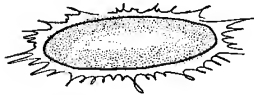
Why!?



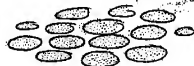
Under the effect of gravity, matter has a natural tendency to **FRAGMENT** into "cells" with a radius equal to the **JEANS RADIUS**. The higher the temperature, the higher it is. If the temperature drops suddenly, the Jeans radius diminishes and becomes less than the radius of the object. There is immediate fragmentation therefore.



The lump contracts and heats up



and suddenly emits UV radiation



this cools it and it fragments

We are seeing a **HIERARCHICAL FRAGMENTATION** phenomenon but in the other direction.

And where will it stop?



FUSiON

The simplest thing to do is to experiment. In this cylinder I'm going to compress matter. We'll see what happens ...

We're watching

BAOUM



What happened?

FUSION, my friend, is fusion. If you compress hydrogen, the nucleii will fuse and that will release energy. If you had also asked me...

Look, it's spitting nastily

The stars are lighting up

Will it last long?

At this rate the youngsters will soon run out of hydrogen, but it won't be long before it calms down.

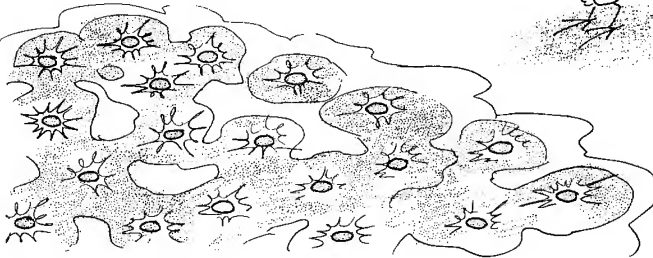
I'm glad about that!



So does all matter turn into stars like that?

Not quite. When a star is born it radiates light with no holding back, as well as matter. In doing so it heats up (and so stabilises) the surrounding matter or dislocates what was painfully being formed around it.

In other words, the **GALAXY** is a mixture of stars that emit a great quantity of **RESIDUAL GAS**.



Stars radiate energy and heat the gas, so increasing the **PRESSURE**...

GALAXY

And the **PRESSURE FORCES** dilate the gaseous halo.

STAR GALAXY

RESIDUAL GAS

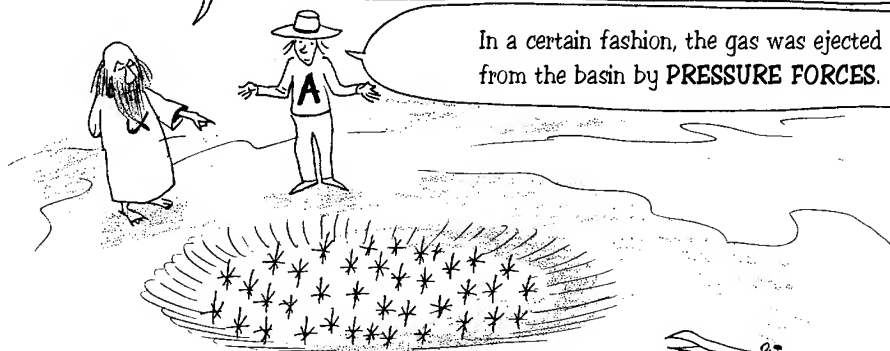
This very massive galaxy (a thousand billion stars) seems to have completely lost its gas. Why?

This "**GALACTIC ATMOSPHERE**" largely overruns the edge of the "**STAR GALAXY**"

It's true! Where has the **RESIDUAL GAS** gone?

It's calmed down now. But when the thousand billion stars of this galaxy suddenly lit up it was a real **OVEN**.

In this way the **THERMAL AGITATION SPEED** (*) attained several hundred kilometers a second, a higher value than the **LIBERATION SPEED**. Then all the atoms of residual gas left the enormous basin of this galaxy.

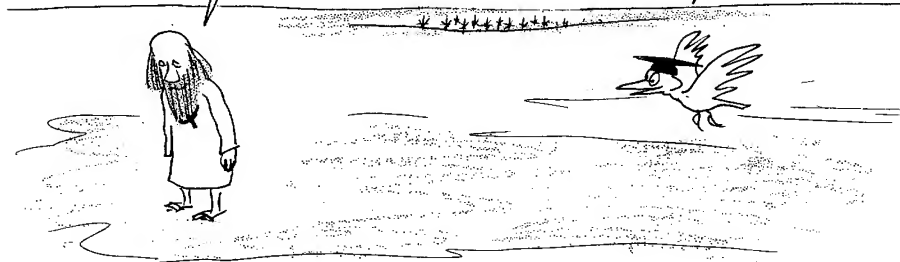


In a certain fashion, the gas was ejected from the basin by **PRESSURE FORCES**.

I suppose that one day it will fall back in?

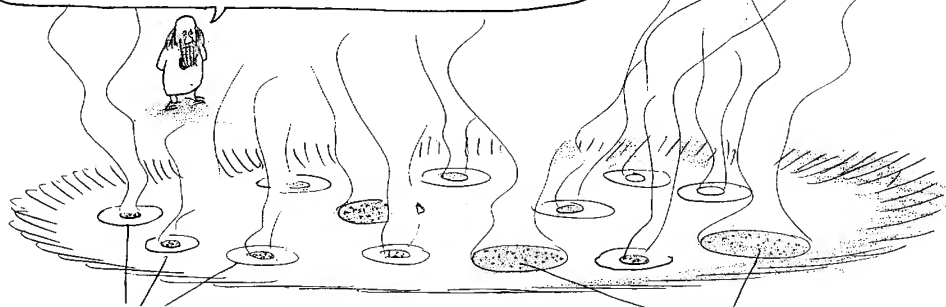
In this case the particles of residual gas have acquired too great a speed and have gone too far. They'll never come back. As well as that, the gas has become extremely rarified.

In other words, the atoms will never meet again and will... conserve their speed forever.



(*) See **FLIGHT OF FANCY**.

The galaxies forming a **CLUSTER** will bathe in this diffuse milieu therefore, brought to millions of degrees but extremely rarified, emitted by heavy galaxies



LIGHT GALAXIES

HEAVY GALAXIES

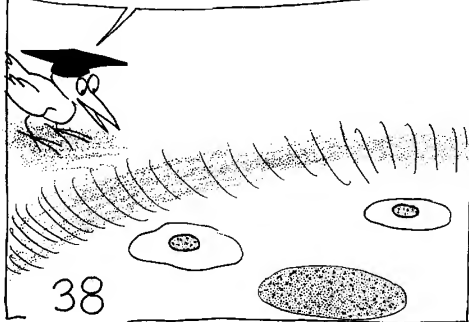
Light galaxies have less violent ovens. They retain their gas.



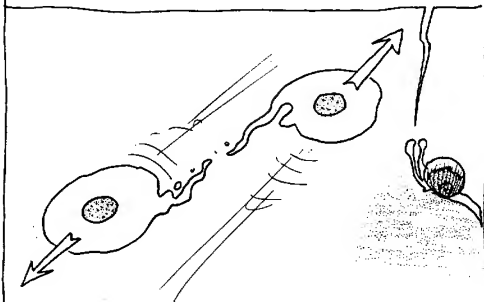
They evolve in the depression-cluster like eggs in a hot frying pan.



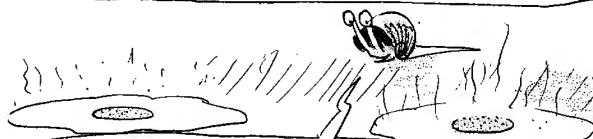
Light galaxies have a "white" and a "yolk", whereas heavy galaxies, called **ELLIPTIC**, only have a large yolk.



The residual gas halos of light galaxies increase the chances that these objects will interact. The rotation movement of the gas halos is accentuated.

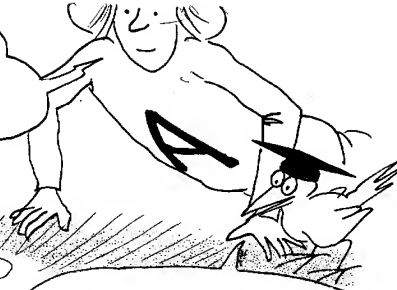


The stars have really calmed down.
In relation to what they were at birth
they've become simple embers



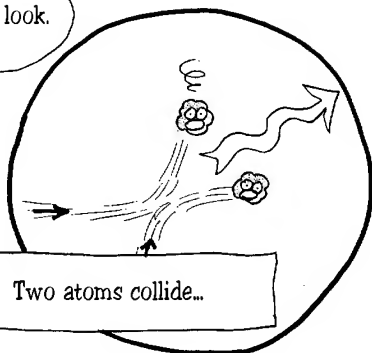
If they'd carried on at that rate
they wouldn't have lasted long.

The residual gas of light
galaxies emits radiation



Where does this radiation come from?

From atoms, look.



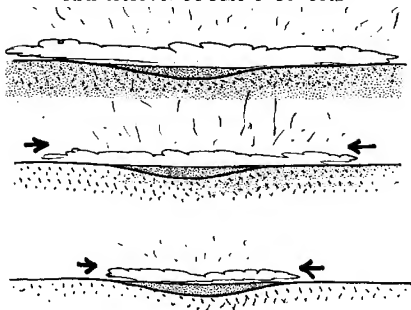
Two atoms collide...

... which is accompanied by radiation
emission. During the operation, a part
of the atoms' energy is converted
into radiant energy.

The atoms' thermal agitation
speed diminishes. This gaseous mass
COOLS and who says **TEMPERATURE**
says **PRESSURE**



RADIATIVE COOLING OF GAS



With the weakening force of pressure, the residual **INTERSTELLAR** gas will quietly return to its place in the "galaxybasin".



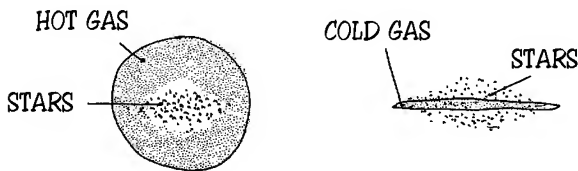
The "white" is back with the "yolk".



The **MODEL** presented here is a **2 dimensional** description (the third dimension being used to represent the curvature, the gravitational field, etc.). **GALAXIES** are three dimensional objects. Galaxies which don't rotate, or very little, would have a shape similar to that of a **SPHERE**. However, galaxies in rapid rotation will be flattened like pancakes. Our galaxy, the **MILKY WAY**, turns on itself over **200** million years.

When the residual gas falls back onto a galaxy, centrifugal force hinders its contraction in the radial direction. However nothing will oppose contraction according to the axis of rotation. Interstellar gas, in galaxies, will have the shape of a **VERY FLAT DISC**.

The Management



If I've understood it correctly, in the Universe there are essentially two types of galaxies:

- Heavy galaxies, elliptical and practically without gas.
- Lighter galaxies, with ten to a hundred billion stars which present themselves as a **MIXTURE** of two gases: the **GAS OF STARS** and **INTERSTELLAR GAS**.

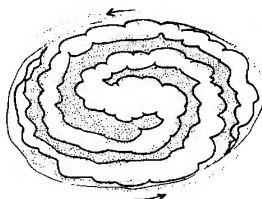
In effect, the **STELLAR SOUP** contains so many stars that it could be compared to the **MOLECULES OF A "STAR GAS"**.

THE SPIRAL STRUCTURE

Look, something very singular is happening: interstellar gases and "star gas" are not revolving at the same speed, so the interstellar milieu becomes **HETEROGENOUS**.

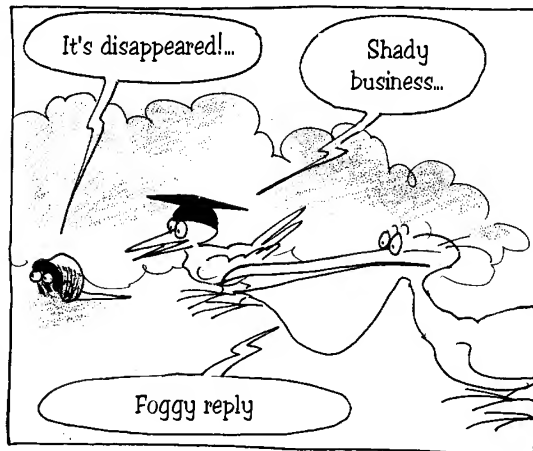
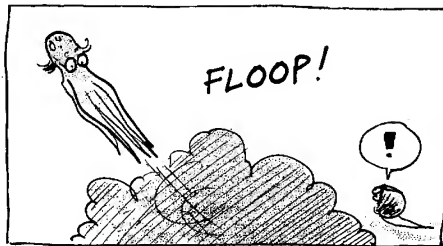
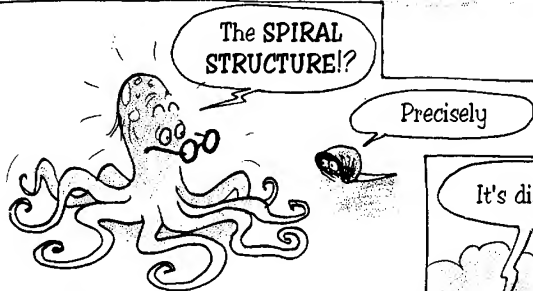
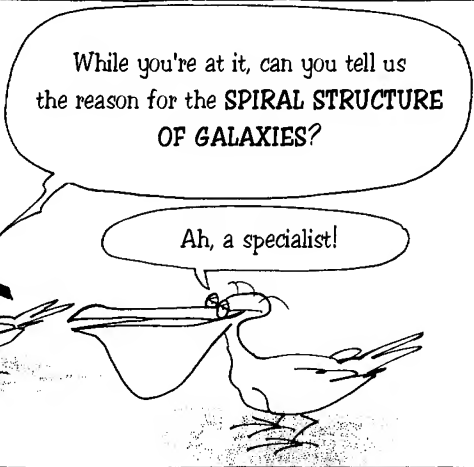
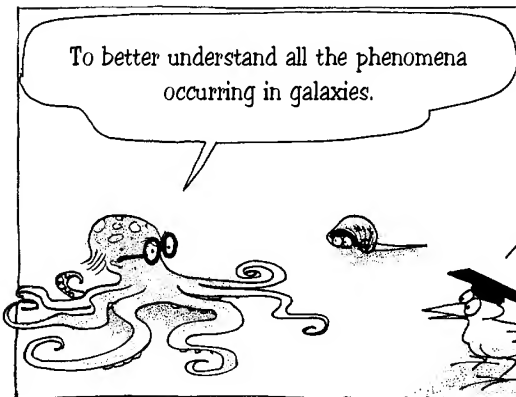
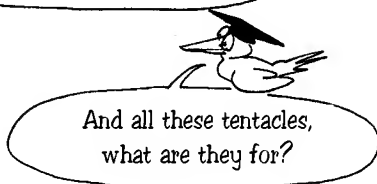
The residual gas revolves more rapidly.

It's distributed in filaments of **SPIRAL** shape

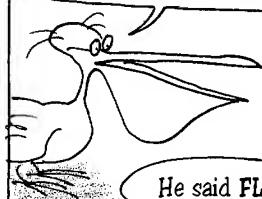




I'm an... astrophysicist.



Did you understand what he said?



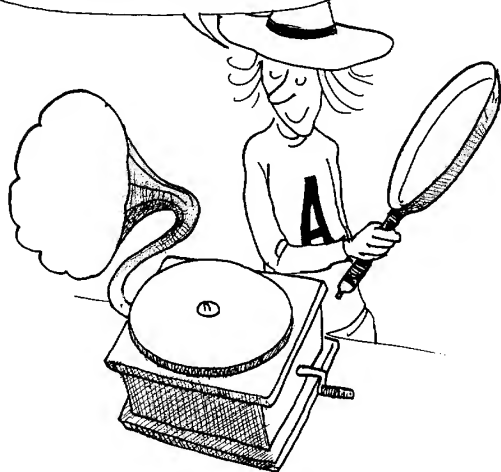
He said FLOOP!



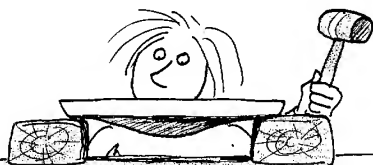
Well I'd like to understand



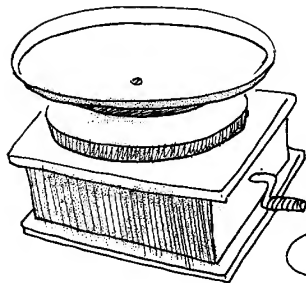
I think I've got an idea



First I deform
the bottom of the pan
like this...



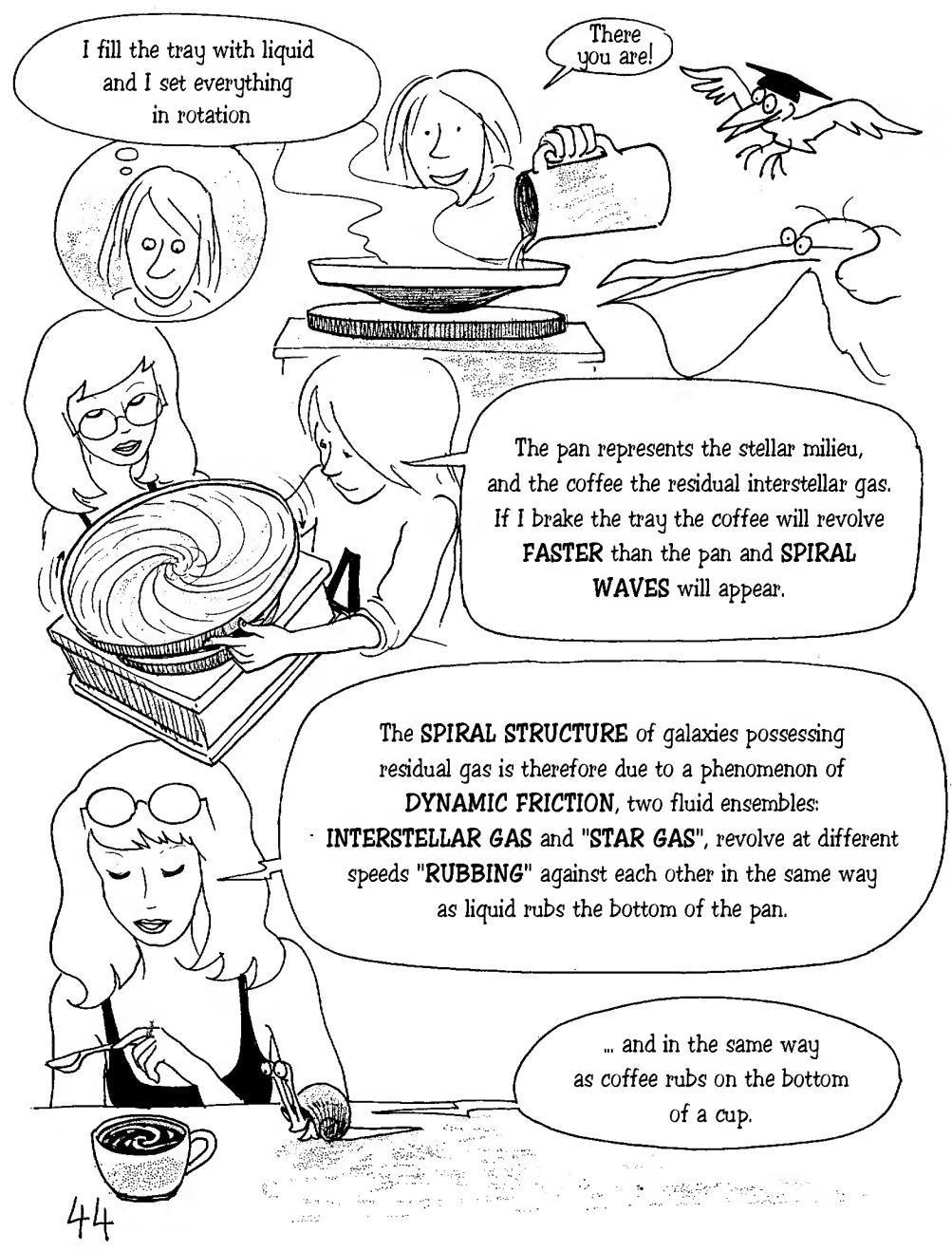
Why did you screw this object
to the gramophone platter?



I don't get it...

You'll see





I fill the tray with liquid
and I set everything
in rotation

There
you are!

The pan represents the stellar milieu,
and the coffee the residual interstellar gas.
If I brake the tray the coffee will revolve
FASTER than the pan and **SPIRAL**
WAVES will appear.

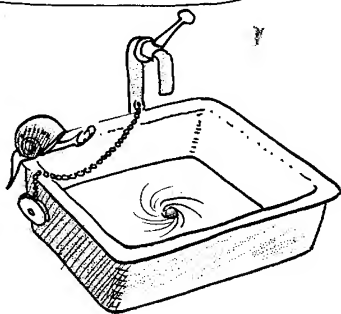
The **SPIRAL STRUCTURE** of galaxies possessing
residual gas is therefore due to a phenomenon of
DYNAMIC FRICTION, two fluid ensembles:
INTERSTELLAR GAS and **"STAR GAS"**, revolve at different
speeds **"RUBBING"** against each other in the same way
as liquid rubs the bottom of the pan.

... and in the same way
as coffee rubs on the bottom
of a cup.

But why don't **ELLIPTICAL** galaxies have a spiral structure?

Simply because they don't have **RESIDUAL GAS**. They lost it at the moment of ignition of their **PRIMARY STARS**.

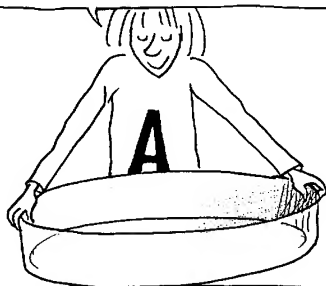
A **DYNAMIC FRICTION** phenomenon is also responsible for creating the spiral structure when a sink is emptied.



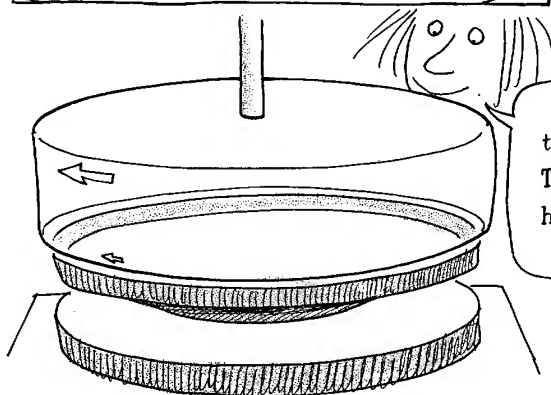
Hmm, what you're saying is serious. So the key to the mystery of spiral galaxies could be found at the bottom of coffee cups or sinks?!?

There we caused an interaction between a fluid and a solid wall. Let's try with a system in which two fluid masses interact.

So could galaxies be the drain holes of the cosmos?



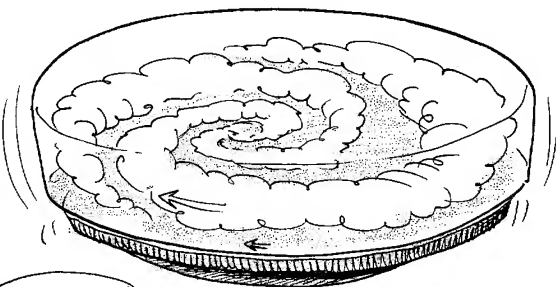
I've imprisoned the gas under this bell jar and put a liquid in my pan. Thanks to this system I can study what happens when a gaseous mass interacts with another fluid mass.



The rubbing together of liquid and gas is relatively weak. It will create very moderate local temperature and pressure fluctuations, a few per cent at most...

but my gas is supercharged with water vapour. It just wants to **CONDENSE** when there is the slightest temperature disturbance (*)

Look! Archibald has made a superb **ARTIFICIAL CYCLONE**



Very pretty!

My word Max, you're right!

In a cyclone, a mass of air supercharged with humidity "rubs" on its fluid support, this creates **PRESSURE** and **TEMPERATURE** perturbations which **SET OFF** the condensation of water vapour. This **SECONDARY** phenomenon violently reveals the **PRIMARY** spiral phenomenon. (**)



OK, but what has that got to do with galaxies? The spiral structure isn't a water vapour cloud after all.

46

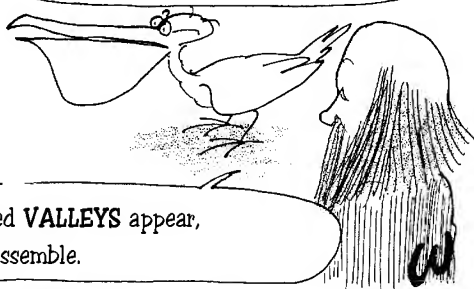
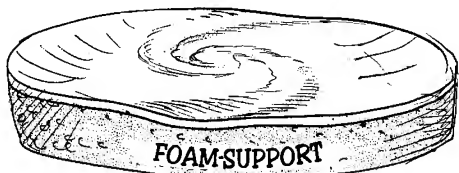
(*) **SUPERCRITICAL** vapour.

(**) A phenomenon which releases heat and feeds the cyclone with energy (but that's another story).

Let's return to our **MODEL** of galaxies. A fluid mass representing the "**STAR GAS**" turns in its "**BASIN**". It is topped by a mass of **RESIDUAL GAS** which revolves slightly faster. **DYNAMIC FRICTION** results and the **MASS** distribution varies, the perturbation having **SPIRAL** geometry.

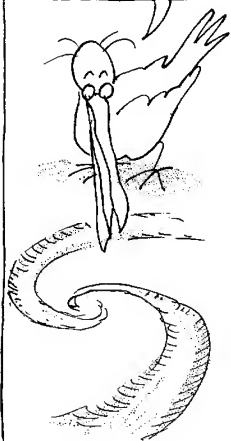


Every concentration of **MATTER** (star or gas) quickly mines into its foam-support. Where there is **MASS** there is **CURVATURE**.



In other words, sorts of spiral shaped **VALLEYS** appear, where gas will tend to assemble.

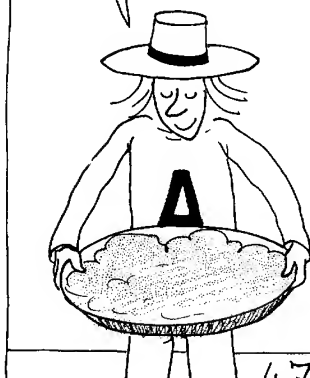
But I still can't see a water vapour concentration.



Let's collect a bit of interstellar gas



Let's look at what happens to interstellar gas when it "falls" into these 'valleys'

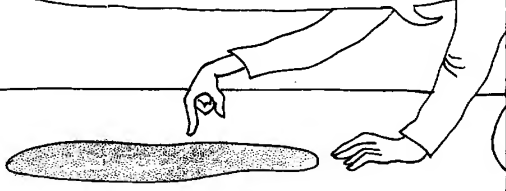


GALACTIC METABOLISM

We'll go into a quiet corner far from any galaxy



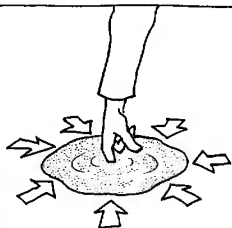
What happens if I create a hollow in the foam-support? The gas will "fall" in...



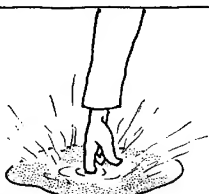
Let's go!



We'll find the same phenomena as those described on pages 32 to 35

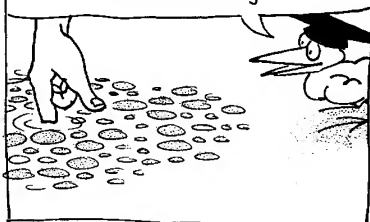


The gas will concentrate and heat up.

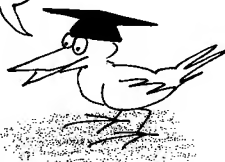
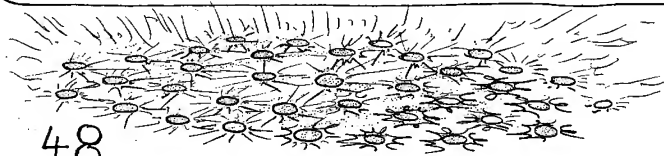


It then cools rapidly by radiation.

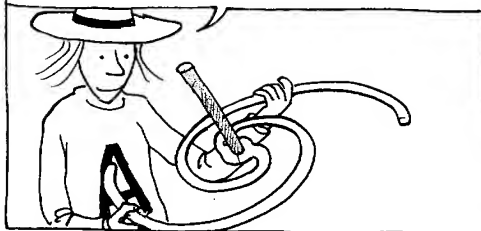
Destabilised, it fragments into a myriad of proto-stars which will immediately...



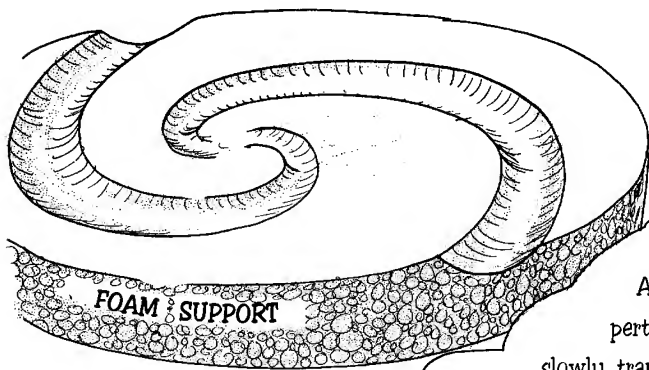
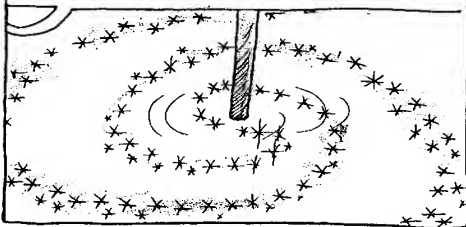
... light up and give **SECONDARY STARS**.



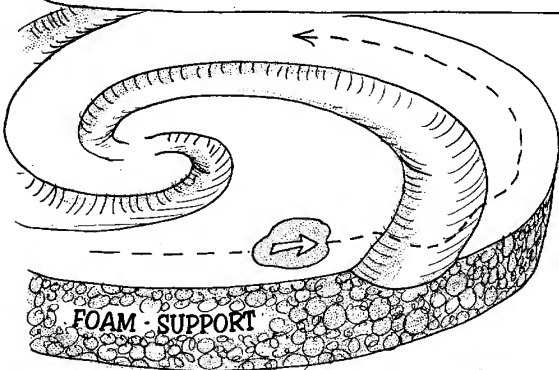
With this sort of ruler
I'm going to create a **VALLEY**



The same thing: stars are born
in the hollows of the valley.

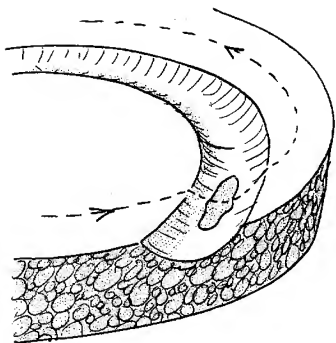


Archibald is right: the spiral
perturbation, revolving very
slowly, translates as these relatively
shallow sides (a few per cent of the general hollow, the "galaxybasin")



The interstellar gas revolves more
rapidly than the spiral perturbation.
Here we see an element of gas
which is about to enter the "valley".

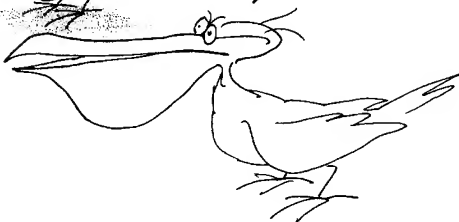




When it arrives at the bottom of the valley it finds itself compressed and gives birth, in passing, to a few **SECOND GENERATION STARS**. Then it quietly leaves. The **SPIRAL ARMS** are therefore the places where new stars are born.



Hmm...



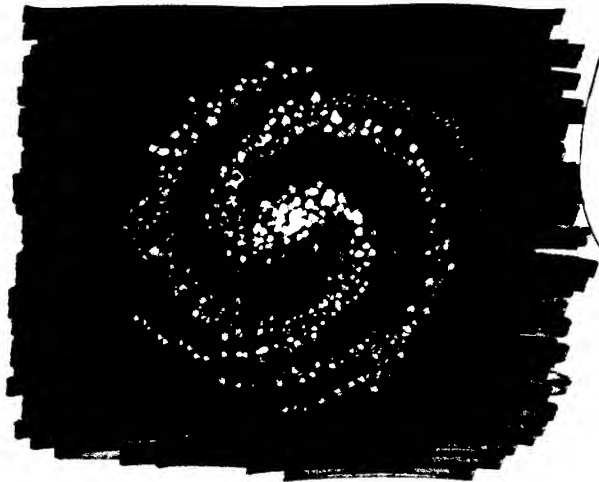
CYCLONES OF THE UNIVERSE

In terrestrial cyclones the initial perturbation is slight but the atmosphere, charged with humidity and therefore **UNSTABLE**, reveals the phenomenon of water vapour condensation.

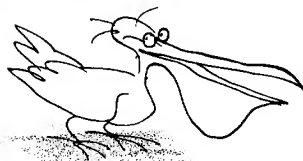


In galaxies, the primitive spiral perturbation is also slight, but **UNSTABLE** interstellar gas reveals the phenomenon by setting off the condensation of matter.





However we only find these young and very hot stars in the arms of the spiral, where they signal their presence by a strong illumination of the stellar gas.

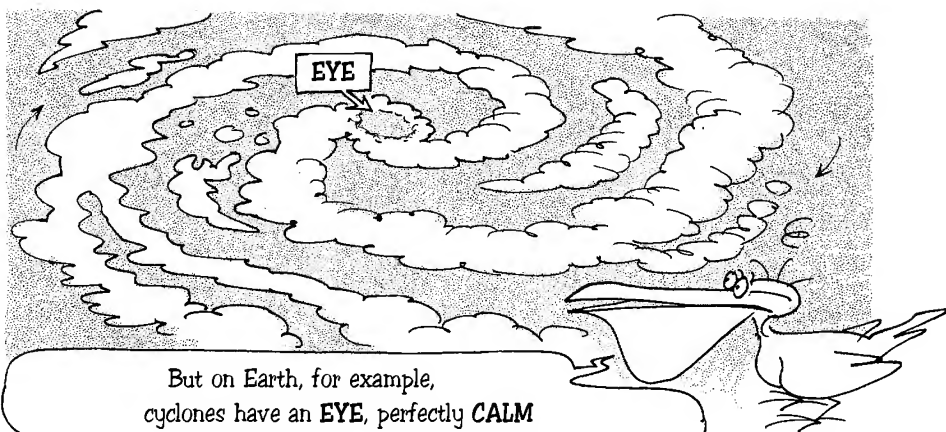


But Leon, you're forgetting that these stars don't remain young for very long. Just long enough to burn a maximum amount of hydrogen. When they leave the arms they are already DYING, they're just embers.

And we can no longer detect them.



INTERSTELLAR GAS too is only clearly visible in the arms, where it is brightly lit by the young stars. Once it leaves the arms it becomes dark.



And you know what, these **PLANET-UNIVERSE** cyclones also have a **CENTRAL EYE!**



DIFFERENTIAL ROTATION

Let's get back to the cup of coffee.



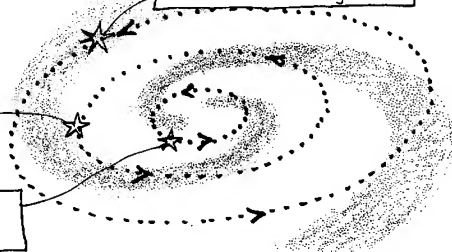
Just as in the cup of coffee, so the objects in a galaxy don't all revolve at the same **ANGULAR VELOCITY**. The Sun, which is at the galactic perihelion, takes 200 million years to go round our galaxy.



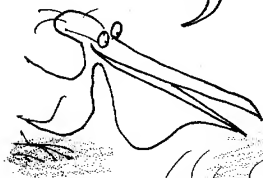
A revolution in 100 million years

A revolution in 50 million years

Sun: a revolution in 200 million years



In short, the centre of a galaxy revolves more quickly than its periphery.



They're sinks, obviously!



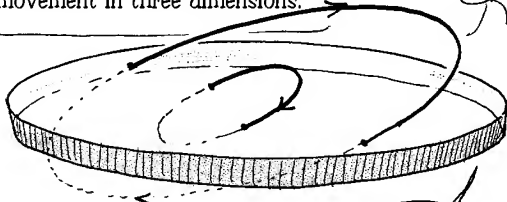
Since Tiresias almost disappeared into a black hole, he's become very wary.



That isn't silly. Lots of very nice people think that there is a big black hole at the centre of galaxies.

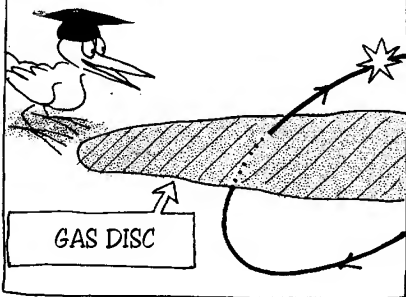


Here's a "REAL" galaxy, with movement in three dimensions.



Schematically, stars, which are elements of "star gas" (so assimilable to "molecules") cross the ultra-flat **GAS DISC** with each revolution

This explains why the interaction 'stellar milieu'-'interstellar milieu' is relatively weak.



I suppose it is because they only interact with the gas when they cross the flat disc.



Exactly!



Firstly, in the centre of galaxies there aren't any stars,
and secondly, their rotation period is shorter.

So in this region the interaction,
the friction between the stellar and
the interstellar milieus, is greater.

Once round in 50 million years.

Consequently, this structure
will be more marked in the central
region and could transform itself
into a **BAR**

Let's get back to the gas. What happens if I let a
lump of **INTERSTELLAR GAS** just do as it likes?

This time we
won't intervene..

We'll just
watch.

The gas is cooling naturally
by radiation. Its Jeans distance
diminishes and it fragments.

In the arms of galaxies the gas also has
a tendency to collect into large lumps whose
radius is equal to the
JEANS RADIUS (*)

But won't these lumps of gas continue to cool by radiating?

Yes, but the young stars born in the clouds will continually reinject energy.

You'll see. We'll do an experiment. I take an ultra-violet lamp

Are you going to tan a lump of interstella matter?

With this type of radiation, which simulates that emitted by young, very hot stars, I heat up the lump. Where there is **HEAT** there is **PRESSURE**, and the increase in internal pressure dilates the gas lump.

If the injection of energy is too violent I could even disperse the matter in the lump by dislocating it.

A question remains: a **STAR... WHAT IS IT?**

STELLAR PHENOMENON

At the centre of a gas lump the temperature and pressure conditions become such that hydrogen **FUSION** occurs, emitting a great deal of energy.




This increases the **PRESSURE** in the centre of the star even more. Don't forget that pressure is only the measure of the quantity of energy per unit of volume.




In short, a **STAR** is a sort of automatic stewpot, it heats up all by itself.

The **DIAMETER** of the star depends on the quantity of energy released. Immediately after its birth the star is extremely rich in hydrogen, so it 'burns' like a madman and dilates considerably.





Then it calms down
and the star goes through a long,
relatively tranquil phase.




It simmers gently

One day the hydrogen
runs out



!?



The "lid" falls in, that is to say
that the star **CONTRACTS**.
The density and temperature
climb and climb


Because fusion reactions consume the helium formed,
then the carbon and silicium, the star often explodes brutally



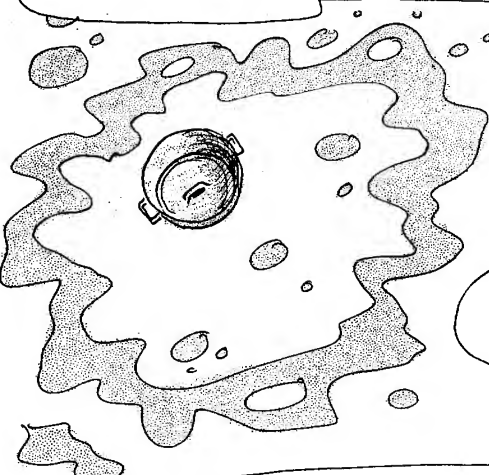
BLOUTCH



The star becomes
a **SUPERNOVA**



Luckily this sort of thing
only happens in a galaxy
once a century



The lid has fallen to the bottom of the pan.
All that remains is a pretty useless object.
A sad end.

But Leon, once a century is a **VERY** rapid rhythm.
Remember, a galaxy takes 200 million years
to revolve on itself.

Heavens,
that makes two
million **SUPERNOVAE**
per revolution!

The **SUPERNOVAE**
project their debris for
hundreds of light
years (*)

Supernovae explode anywhere at any time and maintain
great disorder in the interstellar milieu.

And these supernovae
feed energy back into
the interstellar gas.

CHPAF!

CHPAF!

Another one
that's gone
bang.

Let's go and find
somewhere quieter.

(*) A galaxy has a diameter of a hundred million light years.

TYPES OF STARS

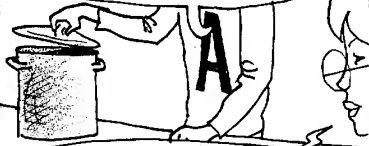


Recipe for making a star;
take a mass M of gas

Cover. Let it infuse
for 100,000 years.



Hmm, I've been waiting quite a while already and... nothing!



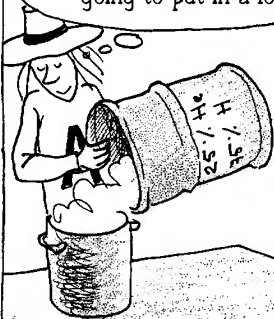
How much did you put in?

I don't know... a tenth of a solar mass



Not enough. **PRESSURE** and **TEMPERATURE** will remain below the threshold

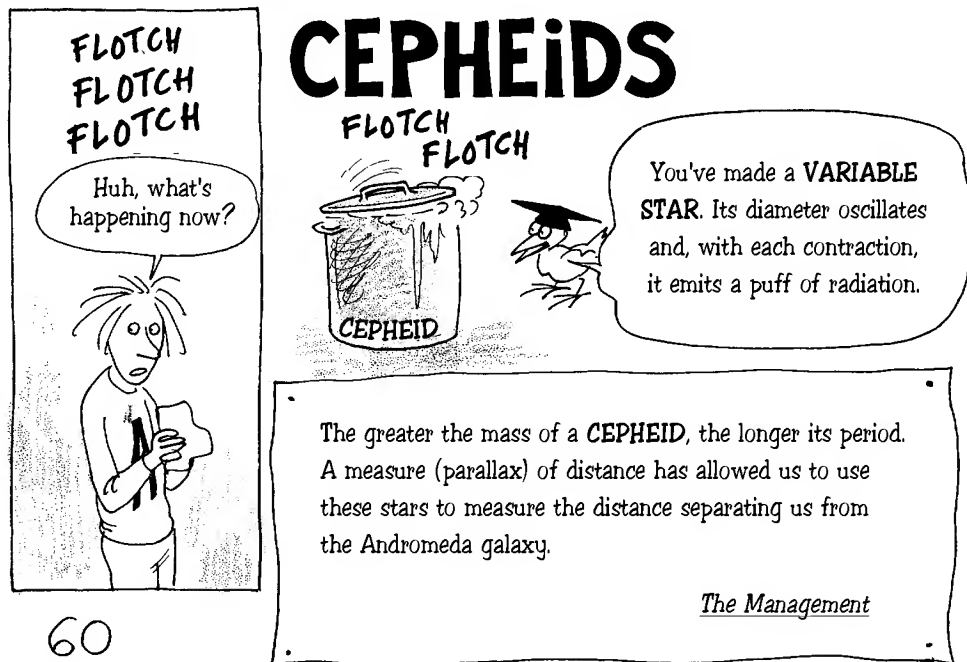
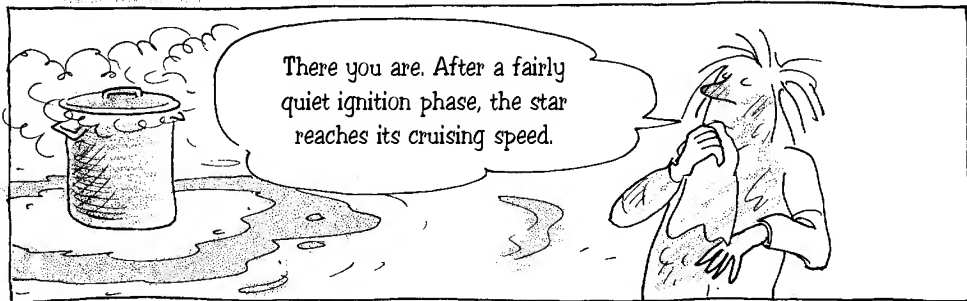
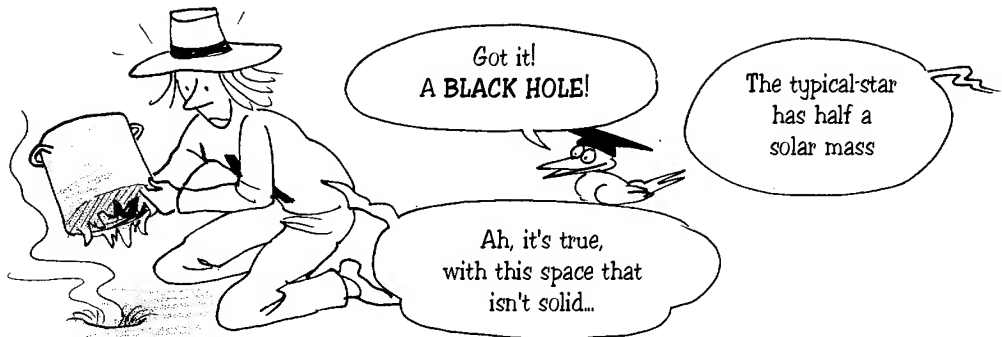
OK. This time I'm really going to put in a lot!



Still nothing. Incredible!



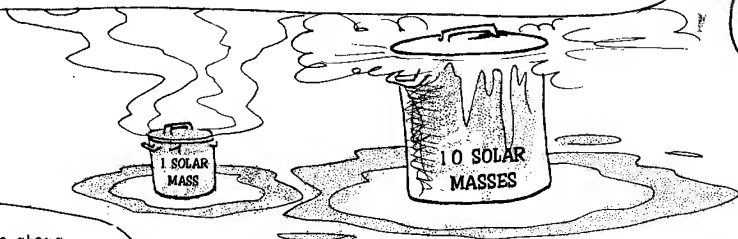
Hello, the cover has disappeared



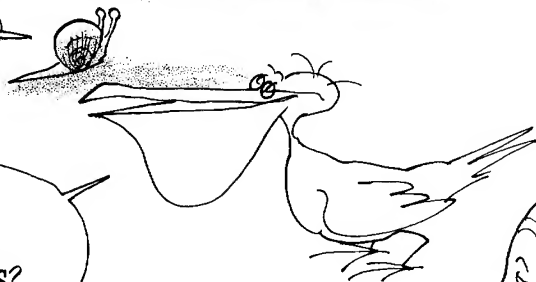
The more **MASSIVE** a star, the **QUICKER** it evolves.

A star of the solar type can burn peacefully for billions of years
but a young, massive star uses up its hydrogen in a million years.

It will have an explosive end.



Massive stars
are stars at risk.



I'm going to ask
Tiresias a question:
WHAT USE ARE STARS?



EXCELLENT QUESTION!

In the heart of stars, nuclei of atoms
are subjected to extremely high pressures.
The **FUSION** of four hydrogen
nuclei gives...



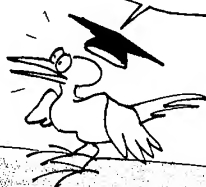
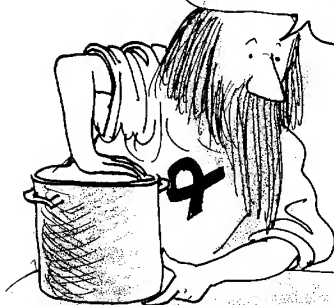
... helium



THE SPORES OF THE UNIVERSE

This star is very close to its instability point.
It has consumed all its hydrogen.
Stand back, I'm going to set it off

Eh, careful!!!



Pretty
isn't it?

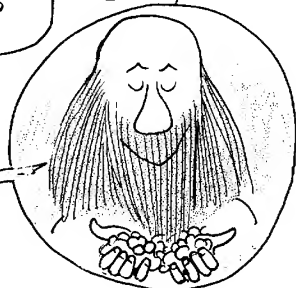
Heavens!



There you are.
Now we just have
to collect up the
oxygen, iron, silicium,
all the atoms of the
MENDELEIEV TABLE

But what use is this
NUCLEOSYNTHESIS?

To make **LIFE**



Heavy atoms agglomerate to give microscopic **DUST**...



...which would serve the **NATURAL CATALYST** to synthesise the **FIRST MOLECULES**



CLOUDS AND RAIN

The matter ejected by stars, either by a slow exhalation or through violent death, reenriches the mass of interstellar gas



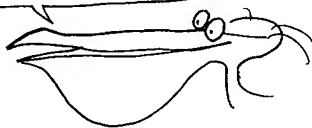
In sum, an atom, chosen randomly, may well have lived in many different stars, especially if it has a heavy nucleus



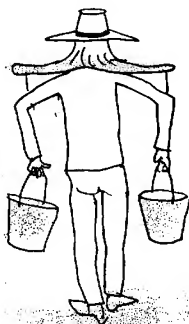
This cycle of the passage of atoms in stars is accompanied by a constant enriching in **HEAVY ELEMENTS**, metals for example: Iron, Nickel, Copper.



So the younger stars are, the richer they are in **METALS**!



Archibald, what are you doing?



Come with me



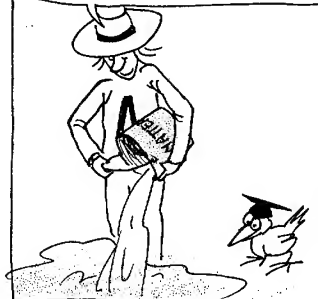
It's time to make a synthesis
of all we know about galaxies



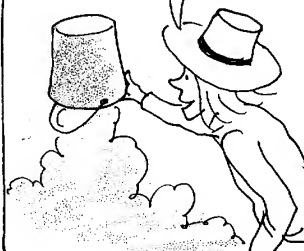
Here I have the best
observational data



Of matter. First,
two hundred billion stars.



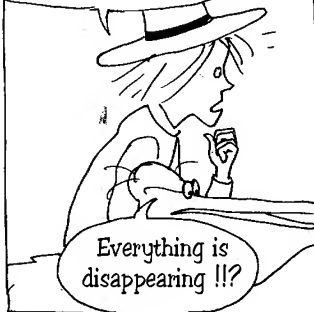
A little bit of
interstellar gas



We make it all turn

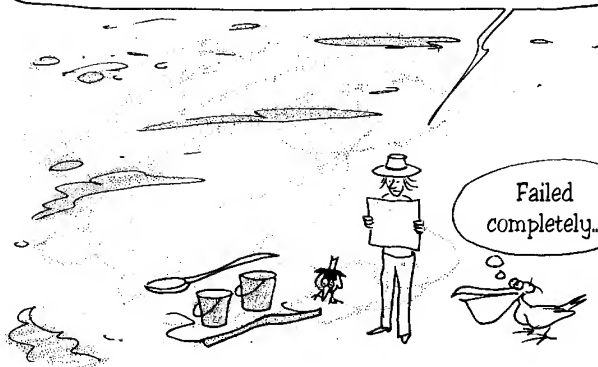


But...
what's happening



Everything is
disappearing !!?

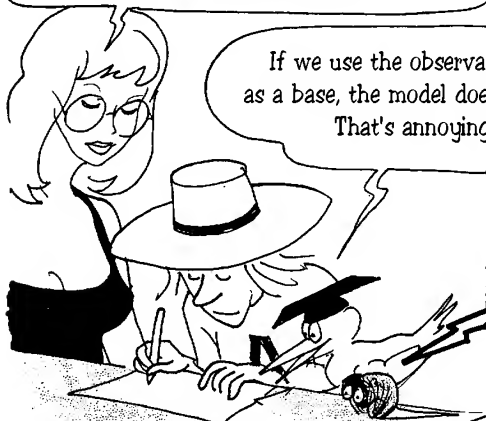
Sophie, I'm dismayed. My galaxy has completely
exploded yet I used the most recent observational data.



Failed
completely...

MISSING MASS


In this representation centrifugal force is stronger than the force of gravitational attraction. The **MASS** involved is **TWO TIMES TOO WEAK**.



If we use the observational data as a base, the model doesn't fit at all.
That's annoying...

In other words:
LOST 200 MILLION STARS.
ANY INFORMATION ALLOWING THIS
MISSING MASS TO BE FOUND
IS VERY WELCOME

We can only count
what we **SEE**



At the end of its life, when it expels a part of its mass, all that remains of the star is a residue called a **WHITE DWARF** or **BLACK DWARF**, usually emitting too weakly to be detected.

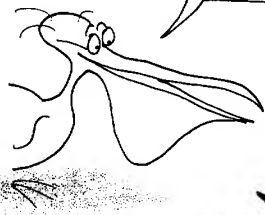
Which means that we're not able to detect the **INVISIBLE MASS** represented by the ashes of the primitive stars formed at the same time as the galaxy.

In an end of the type **SUPERNOVA**,
the external layer of the star explodes.
The resulting retrocompression can compress
the central nucleus to the point where it
changes into a **BLACK HOLE**

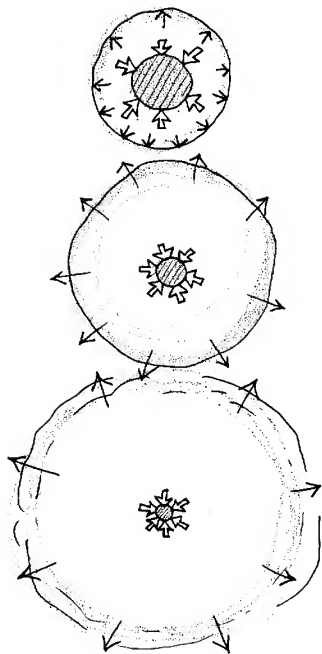


More objects that
will avoid observation

Do any primitive stars remain,
those born at the same time as the galaxy
but that remain detectable?



Yes, in effect, some very old stars
remain grouped in **GLOBULAR CLUSTERS**
which have been burning for about fifteen
billion years. And that in every galaxy,
all born at the same time.




As for the others, they've been dispersed into the four corners of the galaxy, or have become black or white dwarves, or undetectable black holes.

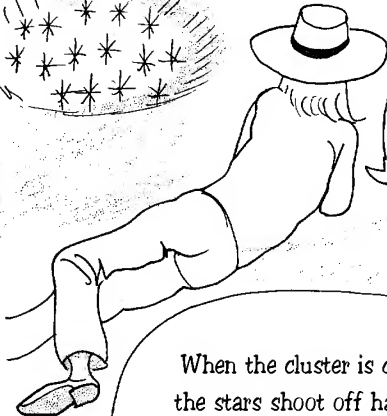


STELLAR CLUSTERS

A globular cluster is a structure of a hundred thousand stars, which has persisted since the birth of galaxies (*)




But galaxies are sprinkled with small, recent clusters, now rapidly being dispersed




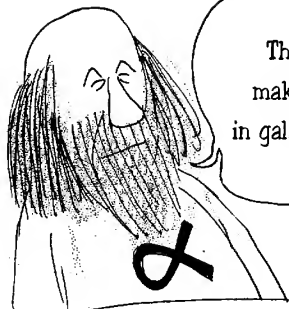
These mini-clusters represent basins with shallow edges where stars, accelerated according to the pot luck of collisions, can escape relatively easily.

When the cluster is dislocated, the stars shoot off haphazardly throughout the galaxy, alone or in couples (**DOUBLE STARS**)



(*) The speed of evaporation of a collisional cluster is proportional to its mass.





The formation of two stars, with similar or different masses, makes a **STABLE** system. These binary systems, very numerous in galaxies, are the sign of an ancient membership of a star cluster.

I suppose that galaxies also lose their stars?

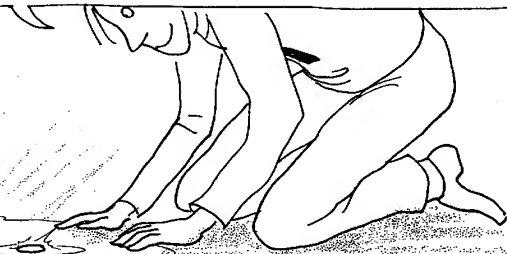


For that to happen, the stars must acquire superspeeds, superior to escape velocity, via **COLLISIONS**. But, dispersed through the galaxy, the stars form an ensemble totally **NON-COLLISIONAL**. They almost never meet, so galaxies don't lose their stars.

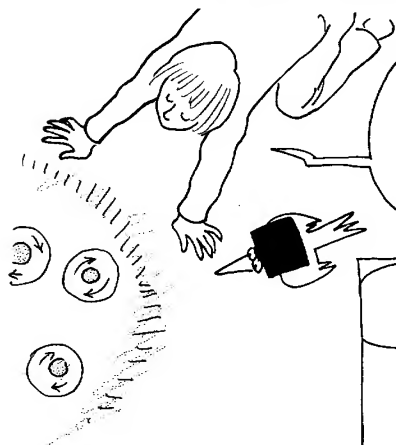


Given the choice, I prefer that...

I'm observing this small cluster of stars that has just been born. Basically they behave like our young galaxies. They are hot and surrounded by a small halo of gas and dust: their atmosphere in a certain sense...



PLANETS

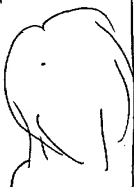
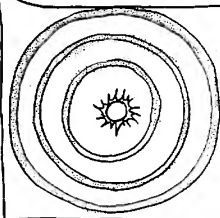


Our young stars go backwards and forwards in their mini-clusters, like fried eggs in a well oiled pan. Collisions set their small halos in rotation.

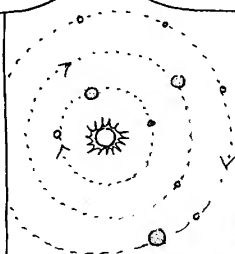
The cluster has dislocated like a spore. The stars have calmed down. I'm one.



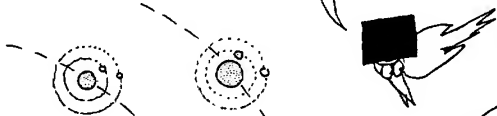
Centrifugal force stops the halo's dust from falling back towards the star. It assembles in concentric rings.



On each circle, each orbit, **PLANETS** form



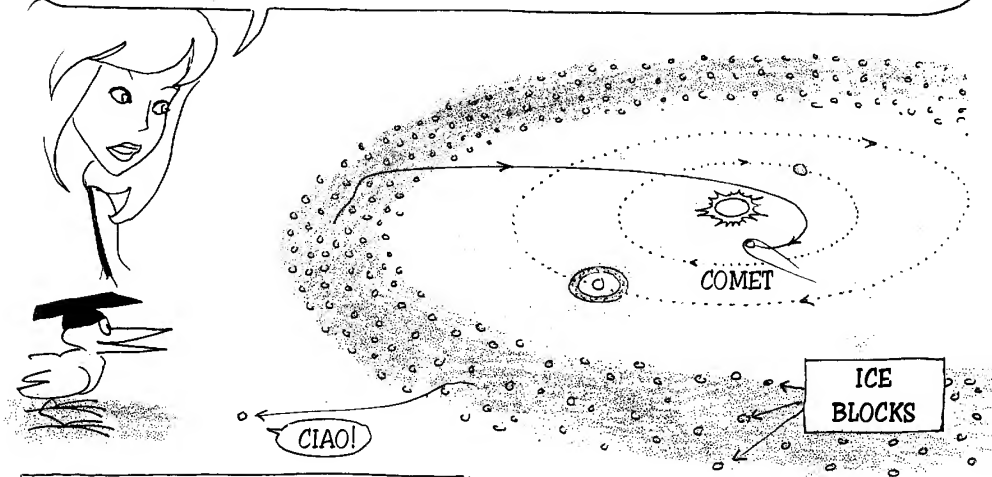
On the same orbit, the biggest planet will capture lighter planets and make them its satellites.



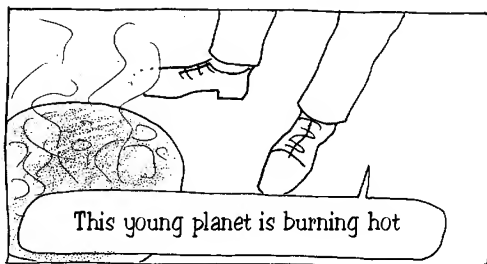
And so the circle is completed.



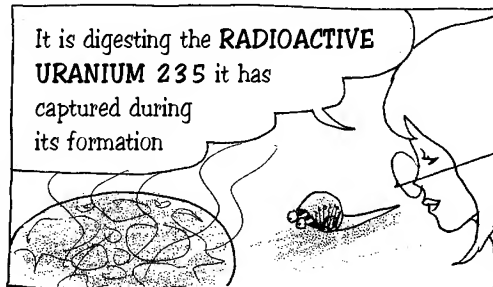
The **GASEOUS** part of this **PRIMITIVE STELLAR ATMOSPHERE** will condense into a sort of **HALO OF DIRTY SNOW**. A collision will occur from time to time between two elements of this belt. Either the bloc will be accelerated, in which case it will exit the **SOLAR SYSTEM**, or it will be slowed down and, in "falling" towards the system's centre, will become a **COMET**.



And what if we take a closer look at these **PLANETS**?



It is digesting the **RADIOACTIVE URANIUM 235** it has captured during its formation



Theres a thing! At the time
of their formation, the planets were
NUCLEAR REACTORS!?

Why **WERE?**
They still are.
How else do you think
the Earth maintains
its core in fusion?

Ah!

It is also heated
by all the meteorites that hit it when it
"DOES THE HOUSEWORK"

Let's have a closer look

Archie, wait for me!! Be careful, the volcanic activity is still intense.

Ah him...
always like a bull
in a china shop

So Tiresias... has your tail
got its curve back again?

Mip!

So here we are on a **PLANET**. Torrential rains
gradually wash away the scars left by meteorites.
We are at $t = \text{ten billion years}$ and the cosmological
radiation temperature has fallen to **4 degrees Kelvin**

We'll be able to start a new story:
The Biologicon. This is Sophie, speaking to you
directly from the Cosmos

END